Comparison of Imaging Radar Scenes at 2,5m and 6cm

PREPARED FOR:
The Department of Electrical Engineering at University of Cape Town

PREPARED BY:
Amy Phillips
PHLAMY002

October 23, 2006

TERMS OF REFERENCE

In July of 2006 the Electrical Engineering Department at the University of Cape Town allocated the students their Thesis topics. This project will aid the RRSG at the University of Cape Town in there research of Synthetic Aperture Radar Sensors. The Project was completed under the supervision of Professor M. R. Inggs. Mr. T. Bennet was also involved in the completion of the project.

My instructions were to:

- Collect Radar images from SASAR and ERS sensors and aerial optical images of the Bot Rivier area near Hermanus in the Western Cape of South Africa.
- Interoperate and Compare the images using ERDAS imaging software.
- Comment on the feature of the landscape best seen using each type of radar sensing image.
- Draw conclusions as to which sensor is most appropriate for detecting features in the landscape, man made and Natural.
- Submit Report on October 23, 2006 to the Department of Electrical Engineering at the University of Cape Town.

EXECUTIVE SUMMARY

OBJECTIVES

The objective of this report is to interoperate and compare images from different Synthetic Aperture Radar (SAR) sensors and decide which images are better for detecting different features of the landscape. The images cover the Bot Rivier Estuary near Hermanus in the Western Cape of South Africa. The sensors used to retrieve images are the South African SAR sensor (SASAR 1) and the European Radar Sensors (ERS 1 and 2). Optical images obtained from the Department of Surveys and Mapping and Google Earth are used to confirm my findings.

BACKGROUND

The SASAR 1 sensor operates at VHF (141 MHz) and has all four polarisation settings i.e. HH, HV, VH, VV. The ERS sensor operates in the C – band (5.3 GHz) and has only VV polarisation.

There are a number of factors to consider when interpreting the objects in a radar image. These include Shape, Size, Tone, Texture and Association. If used in the right way these can be clues to identifying objects and features.

To further ease the process of image interpretation the images are registered. In this process all images from the different sensors are mapped onto one co-ordinate system where each pixel corresponds to a particular co-ordinate. The optical images are also mapped to this co-ordinate system. This allows me to compare the images pixel by pixel.

SAR Sensors

An SAR sensor is a system and all systems have certain parameters. In this case I look at wavelength and polarisation. These two parameters will affect the way the electromagnetic wave interacts with the surface. They must be chosen according to the features one wishes to detect. For example, a longer wavelength is able to penetrate deeper into the surface volume giving insight into the vegetation type.

Distortion in radar images can occur in numerous ways. Most likely the largest cause of distortion is the radar signal arriving back at the sensor at the wrong time i.e. earlier or later than it should relative to the surroundings. This can result in layover or foreshortening effects.

The Target will also have parameters which will affect the way that energy is sent back to the sensor. These include surface roughness, the dielectric constant of the surface material and size of the target compared to the wavelength. These parameters can cause scattering or Bragg resonance.

The Main purpose of SAR technology is its ability to improve the azimuth resolution. The azimuth resolution is independent of the altitude of the sensor and depends only on the size of the antenna. A smaller antenna will result in a finer resolution.

Doppler shift theory is an alternative way of calculating the azimuth resolution. The sensor uses the Doppler echoes to determine the distances between points in the ground.

IMAGE PROCESSING

The Image processing of the SASAR 1 and ERS images was done by Minette Lubbe at the CSIR. The two methods used are Principal Component Analysis and Image fusion.
Principal component Analysis involves a linear transform. The covariance matrix from the original data is used to find the Eigen values and Eigen vectors. The Eigen values are the coefficients for the linear transform. The Highest Eigen value results in the first principal component. It has the highest variance and hence it contains the most information about the original data set. The first four principal components are the most relevant as the contain ninety nine percent of the original data..

Two different types of image fusion where done, Standardised Principal Component Analysis and Intensity, Hue and Saturation. Both these techniques involve substituting one of the image channels with a high resolution optical image.

INTERPRETATION AND COMPARISONS

This is the analysis part of the report. I look first at the man made features. These include Buildings, power lines and roads.
Individual buildings and small clusters are detected in the SASAR VHF images. Urban areas such as Kleinmont and Hermanus are detected in the SASAR and ERS images. Roads are generally undetected. They are only detected by the SASAR sensor when by lined be trees. Power lines are seen as bright stripes and pylons are seen as bright spots. These are only detected in the SASAR images.

Natural features such as vegetation are not detected by the ERS sensor and seen only by the SASAR sensor. This is because the c-band frequency of the ERS sensor does not allow the signal to penetrate the surface volume.
Water bodies are well detected by the ERS sensor as ocean backscatter improves as the frequency increases.
Relief such as mountains, ridges and ravines can be made out clearly in the ERS images. The higher frequency is more sensitive to these kinds of changes in the terrain. The speckle caused by constructive and deconstructive interference is more evident in the SASAR VHF images because of the lower frequency.

CONCLUSIONS

The SASAR sensor can be used for detecting man made objects such as buildings, urban areas and Power lines. It can also be used for detecting various types of vegetation. Ambiguities may occur when classifying areas of dense forest and urban areas as they appear very similar in the SASAR images. A koppie may be confused with an individual building.

The ERS sensor would be the appropriate choice for detecting water bodies, shore lines and types of relief.

TABLE OF CONTENTS

LIST OF ILLUSTRATIONS

TABLES

page

FIGURES

GLOSSARY

RRSG Remote Radar Sensing Group

CSIR Counsel for Scientific and Industrial Research

SAR Synthetic Aperture Radar

VHF Very High Frequency

SASAR South African Synthetic Aperture Radar

ERS European Remote Sensing

FCC False Colour Composite

RGB Red, Green and Blue

PRF Pulse Repetition Frequency

PCA Principle Component Analysis

IF Image Fusion

SPCT Standardised Principle Component Transform

IHS Intensity, Hue and Saturation Transform

EM Electro-Magnetic

1 INTRODUCTION

1.1 SUBJECT OF THIS REPORT

This Report describes the interpretation and comparison of certain radar images of the Botrivier area near Hermanus in the Western Cape of South Africa. In order to do the analysis it is important to understand the fundamentals of SAR technology. The first two chapters of the report aim to familiarize the reader with the important aspects of SAR technology. Chapters Four and Five involve the practical application of the SAR principles to process and interoperate the radar images.

1.2 BACKGROUND TO INVESTIGATION

In this project I will utilise three different types of images. These include two different types of radar images and high resolution optical images of the site. The radar images were sourced from the SASAR I VHF imaging radar and the ERS1/2 satellites. The optical images where obtained from the Department of Surveys and Mapping and Google Earth. The images where then co-registered, a process which will be explained later, by the RRSG at the University of Cape Town. The image processing was done by the CSIR. The CSIR used ERDAS Imaging software to do the image processing. I used ERDAS Imaging software for all the analysis and interpretation which is documented later in Chapter Five.

1.3 OBJECTIVES OF REPORT

The objective of this report is to interpret and compare the images using suitable image processing software such as ENVI or ERDAS. The comparisons must then be used to highlight features of the landscape which are best seen with each different type of image. Another main objective is to familiarize the reader with SAR technology.

1.4 LIMITATIONS AND SCOPE OF INVESTIGATION

The Data used in this report i.e. the Radar images from SASAR 1 and ERS 1 and 2 where already processed and registered. I do not have first hand knowledge of the techniques used. I was able to research the documentation of the processes involved and combined with other recourses I have come to understand the methods.

However, the scope of this report is to analyse the processed data and come to a conclusion as to which type of data is best suited for detecting different features of the landscape. A limitation here is an insufficient knowledge of the site. A site expedition would be useful in eliminating any errors resulting from this limitation. This expedition took place on October 12, 2006.

1.5 PLAN OF DEVELOPMENT

Chapter Two starts with a brief background of the images and the radar sensor parameters. Following, is a short overview of the image registration techniques and image interpretation. Chapters Three and Four focus on the SAR sensor and provide information on the theory, image processing methods and applications. In Chapter Five I make direct comparisons of all three image types and draw attention to those features which are most prominently seen using each type of image.
Chapter Six will reveal relevant conclusions and lastly recommendations are made based on the conclusions.

2 BACKGROUNDS

In this chapter I will give a brief account of the origins of the radar images and the aerial photographs. I will also explain a little about the visual interpretation of the images and how the images are registered. The image registration facilitates the visual interpretation.

2.1 IMAGE DETAILS

2.1.1 LOCATION

The images from SASAR I (South African SAR) and the optical images cover the Botrivier estuary near Hermanus in the western cape of South Africa. The ERS (European Radar Sensors) images cover greater Cape Town and extend outwards towards Hermanus. Figure 2.1 below shows a rough indication of the areas captured by each sensor. The focal point in all of the images is the Bot Rivier Estuary. On the western and eastern side of the estuary is mountainous terrain. In the valley it is mainly grass lands and cultivated areas. Along the coast on either side of the estuary there are small urbanized areas.

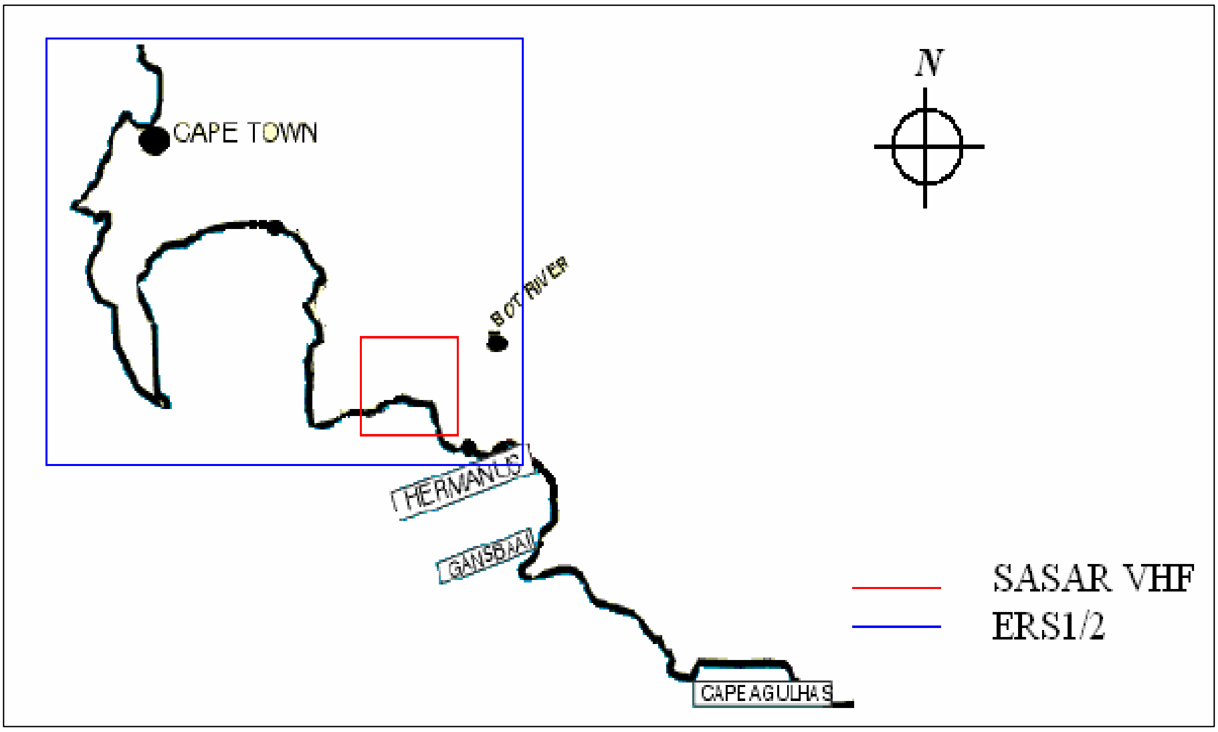

Figure 2.1: Regions Captured by Radar Sensors.

2.1.2 SASAR I

The South African Synthetic Aperture Radar (SASAR) is a system which operates in the VHF band. The system was initially developed by The University of Cape Town (UCT) and Houwtek. In 1995 the project was taken over by Defencetek and underwent further development.

By 1998 the system was installed in a C47 Dakota aircraft and test flown.

SASAR's purpose is to advance SAR technology in South Africa and extend it to potential clients.

The System will also create research opportunities such as the research to be conducted in this report. [8]

Table 2.1: SASAR 1 Parameters [8]

SASAR I System Parameters	
Frequency	141 MHz
Bandwidth	12 MHz
Peak Power	1 kW
Polarisation	VV, HH, VH & HV
Imaging Altitude	4 Km
Finest Resolution	12.5 m
Near Range	3 km
Far Range	40 km
Swath Width	24 km
Date	December '99

2.1.3 ERS I AND II

The European Remote Sensing satellites were developed by the European Space Agency. They orbit the earth in one hundred minutes and in thirty five days have covered nearly the entire planet.

ERS 1 was launched in July 1991 and ERS 2 was launched in April 1995. [9]

Table 2.2: ERS Parameters [9]

ERS 1/2 System Parameters	
Frequency	c-band 5.3GHz
Bandwidth	0.01 MHz
Peak Power	4.8 kW
Polarisation	VV
Imaging Altitude	780km
Swath Width	80.4 km
incidence angle	23 degrees (mid swath)
Date	May '98

2.1.4 Optical photos

The optical images are aerial photographs and have a scale of 1:50 000. These images are very large as a result of high resolution. They have been partitioned into regions covering the east, west and northern sides of the Estuary. High resolution aerial photos where also obtained from Google Earth and from the

2.2 Visual Image Interpretation

2.2.1 Size and Shape

The size of an object relates to the SAR parameters – scaling and magnification. High resolution SAR can enlarge an image ten times with little loss of detail. SAR resolution has the advantage that it is independent of range.

Geometric shapes and patterns are essential clues for identifying natural and especially man made features.

2.2.2 Tone

The tone in an SAR image is an indication of the strength of the backscatter from a certain area on the ground. The average backscatter over one resolution area is seen as the tone or grey level of that pixel. This in turn makes up the tonal changes of the image. The average backscatter is a function of the following:

Wavelength
Depression angle
Polarisation
Aspect angle or local incident
Complex dielectric constant
Surface roughness relative to wavelength
Depth of continuity layer penetrated
Complex volume scattering coefficient

2.2.3 TEXTURE

Special patterns and tonal variations make up the texture of an image. By noticing contrasting textures one can locate areas that have similar surface properties. Factor which affect the texture of an image are dynamic range, processing and image resizing. Texture occurs on three scales:

- **Micro-scale texture** - This is also known as speckle. See section 3.5.3
- **Meso-scale texture** - spreads over several pixels. Identifies vegetation distribution etc.
- **Macro-scale texture –** can be considered as pattern. Identifies whole areas usually within a boundary

.

2.2.4 ASSOCIATION

Clues to an object's identity can be obtained by identifying the surrounding objects. Many objects are closely related and the identity of one can confirm the identity of the other.

2.3 IMAGE REGISTRATION

The co-registration of the radar images in question was performed by Gavin Doyle, a geologist and ERDAS expert.

Image registration is required when you have several radar images of the same scene, acquired by different methods or taken at different times, and you wish to do a direct comparison. Image registration is a technique that creates a co-ordinate system for the images so that each pixel of the image corresponds to a co-ordinate of the scene or reference image.

To briefly explain image registration I will break the process down into four steps.

- Locating Control Point Candidates (CPCs). These are usually obvious points such as a significant land marks.
- Control point matching. The CPCs are recognised in the sensor image as well as the reference image. It is then ensured that they correspond correctly.
- Estimation of Mapping Model. Estimate a transform that relates the sensor image to the reference image.
- Re-sampling and Transformation. Use the developed transform to map the sensor image over the reference image. [7]

In this case the reference image was an aerial photo mosaic which was divided into 18 orthorectified images. A number of geometric models where used to find the best registration process. These included rubber sheeting and high order polynomials. A simple first order polynomial was used to avoid distortion caused by higher order transforms. This involved a simple rotation. The images were then re-sampled using cubic convolution. [11] [12]

3 SAR SENSORS

Chapter Three aims to familiarize the reader with the fundamentals of SAR Sensor technology. I will cover SAR system parameters, Radar imaging geometry, Distortion, Target parameters and SAR principles. I will touch briefly on system design.

3.1 RADAR SYSTEM PARAMETERS

3.1.1 WAVELENGTH

Limitations and Constraints

There are a limited number of frequency bands available in UHF and SHF regions of the EM spectrum that can be used for SAR purposes. The reason for this is to eliminate interference with military and other transmission bands. Letters are used to label the bands that are used for radar imaging. For example, c – band which is used by the ERS 1 satellite.

Consequences of choice

The wavelength will determine the way that the EM wave interacts with the ground surface. Radar wavelengths are sensitive to roughness and moisture. The wavelength can be chosen so that certain ground cover can be penetrated. For most materials concerning microwave remote sensing, penetration varies linearly with wavelength. For example, an L-band signal with wavelength equal to twenty centimetres will penetrate ten times deeper than a K_u-band signal with wavelength equal to two centimetres. Therefore, certain wavelengths can provide more information about the volume of the surface layer, e.g. vegetation, snow, and soil.

3.1.2 POLARISATION

Polarisation describes the orientation of the electric field vectors. However, the structure of the wave can be adapted so that the wave carries information.

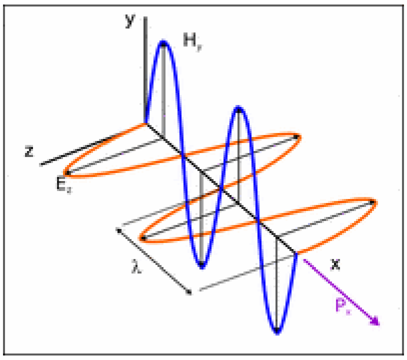

Figure 3.1: Polarization of EM wave

H = Magnetic field
E = Electric field

H and **E** are perpendicular to each other. The EM wave in figure 3.1 has a horizontal orientation because the electric field vectors are in the horizontal direction.

The majority of Image Radars use horizontal polarisation. However, the returned energy may not be horizontal. Some surfaces can change the polarisation of the reflected waveform. Polarisation must be chosen in accordance with the ground targets being analysed.

3.2 RADAR IMAGING GEOMETRY

3.2.1 DEPRESSION ANGLE

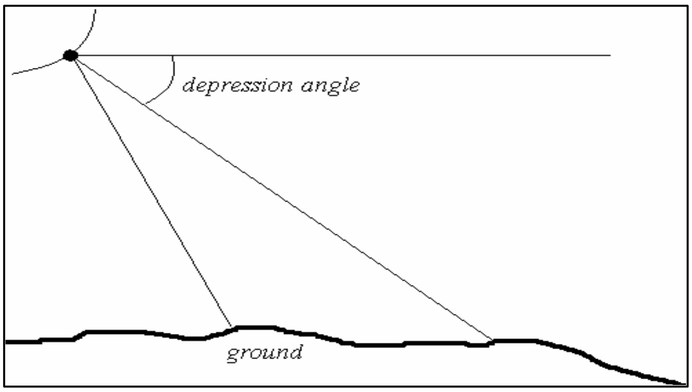

Figure 3.2: Depression angle

An alternative terminology to the depression angle is the incident angle.

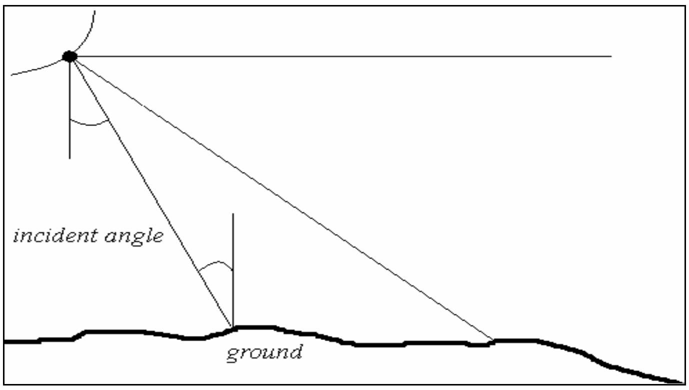

Figure 3.3: Incident angle

3.2.2 LOOK DIRECTION

This is the angle between geographical north and the direction in which the radar is pointing. Keep in mind that the radar points in a direction perpendicular to the flight path.

3.3 DISTORTION

An oblique orientation of the radar sensor is required to create special separation in the radar images. Due to this oblique orientation, certain distortions are inevitable.

3.3.1 SLANT RANGE AND GROUND RANGE

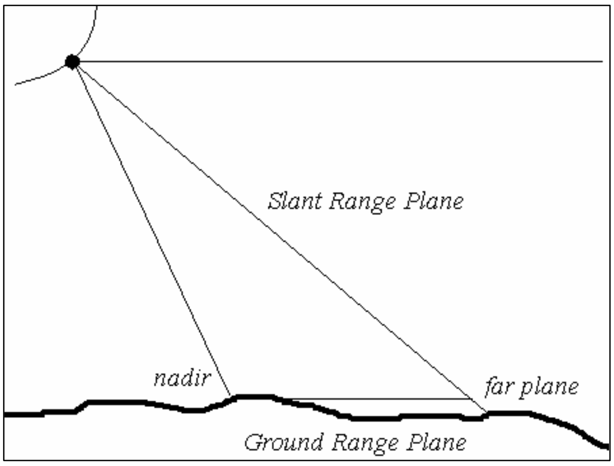

Figure 3.4: Slant range and Ground range

Radar imagery can be formatted in two ways; slant range format and ground range format.

Slant range display: - A point on the ground, represented in the image, is determined by its slant distance.

Ground range display: - position of the point on the ground is found by measuring the horizontal distance from the nadir to that point.

Slant distortion is due to the scale changes from the near range relative to the far range. On a flat surface it is simple to correct as it just a simple trigonometric function. However in an area that has relief exact height levels are required.

3.3.2 LAYOVER EFFECTS

This is the result of a signal arriving too early relative to its ground position. A typical example is a signal reflected off a mountain summit arriving before the signal reflected from the mountain base. The resulting image will show a displaced mountain top. In figure 3.5 below you can see how the mountain top is displaced in the slant range display. The Mountain top labelled B appears before the mountain base labelled A.

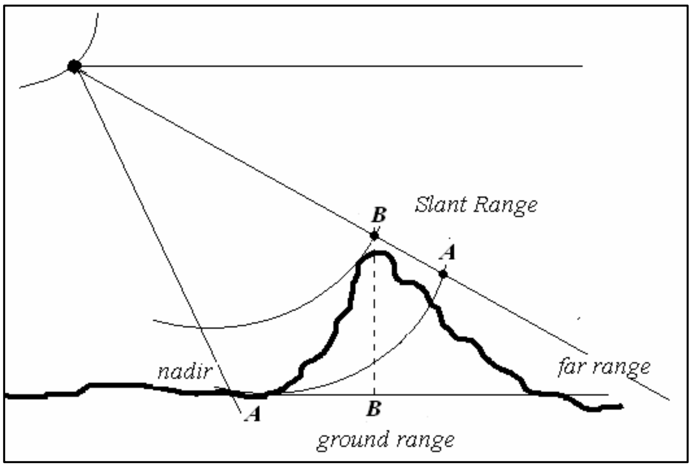

Figure 3.5: Layover effect of Mountain top

3.3.3 Foreshortening Effects

This effect can make a long gradual slope look like a short steep slope in the slant range. Figure 3.6 shows an illustration of how this could occur. The base of the slope a, is reflected onto the slant range and appears closer to the top of the slope b.

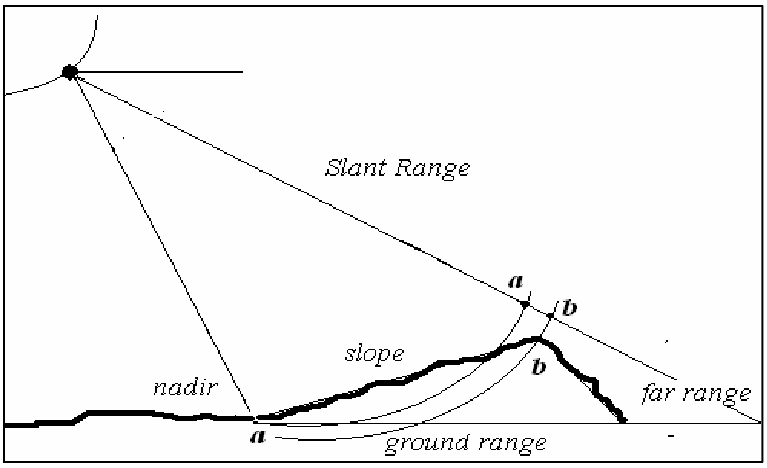

Figure 3.6: Foreshortening in the slant range

The worst case is when the slope is perpendicular to the incident beam. Base and peak of the slope occupy the same position in the slant display.

3.3.4 Radar Shadow

A radar shadow is like a shadow caused when light is blocked by an object. Only in this case the radar signal is blocked by the object and no return signal is possible from behind that object.
This creates a dark area in the image known as a radar shadow.

With a decreasing depression angle in the far range shadowing becomes more evident.

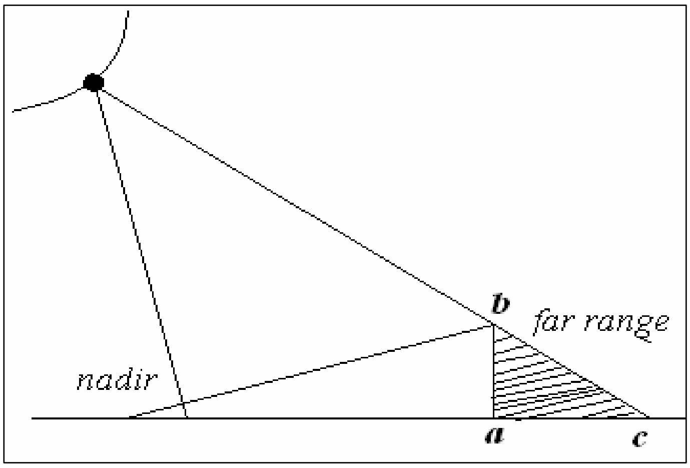

Figure 3.7: Shadowing occurring in the triangle ***abc***

3.4 RADAR TARGET PARAMETERS

In this section we look at how energy is scattered and reflected. In particular we look at surface scattering, volume scattering, specular reflection, reflection back to the sensor and attenuation of the radar signal within a layer of dispersed scatter. The amount of back scattering depends on surface properties such as roughness and moisture.

3.4.1 ROUGHNESS

Surface roughness is variations in height (in centimetres) above or below a reference height. A rough surface will cause incident energy to diffuse resulting in scattering. Surface roughness is closely related to the wavelength used. [2]

3.4.2 COMPLEX DIELECTRIC CONSTANT

The complex dielectric constant consists of a real part, permittivity, and an imaginary part, conductivity. A high dielectric constant depicts a strongly reflective surface meaning that little energy is absorbed. [2]

3.4.3 SCATTERING

Surface

Surface scattering is strongly related to surface roughness as mentioned above in 3.4.1.

Volume

Volume Scattering involves penetration of the upper discontinuity layer of the target volume. Signals are returned from targets below the surface. [2]

3.4.4 POINT TARGETS

Point targets are a result of dihedral corner reflectors. This is caused when two plane surfaces are at 90 degrees to each other and orthogonal to the incident radar. Usually they are man made objects such as buildings. They produce strong reflections and have disproportional returns. They appear as bright spots on an image. [2]

3.4.5 BRAGG RESONANCE

If the radar signal has a wavelength with comparable dimensions to sporadic features on the surface, resonance effects may arise under special conditions. This can result in strangely high radar returns classified as Bragg Resonance. [2]

3.5 SAR PRINCIPLES

SAR improves the azimuth resolution. SAR uses the fact that the target stays in the beam footprint for a number of locations along the flight path. SAR can be explained in two ways.

Synthetic Array Approach

An array of antennae is equivalent to one antenna moving along the array. Received signals are coherently recorded and then combined. The radar sensor is moving with velocity v and the antenna has length L. The sensor is at height h.

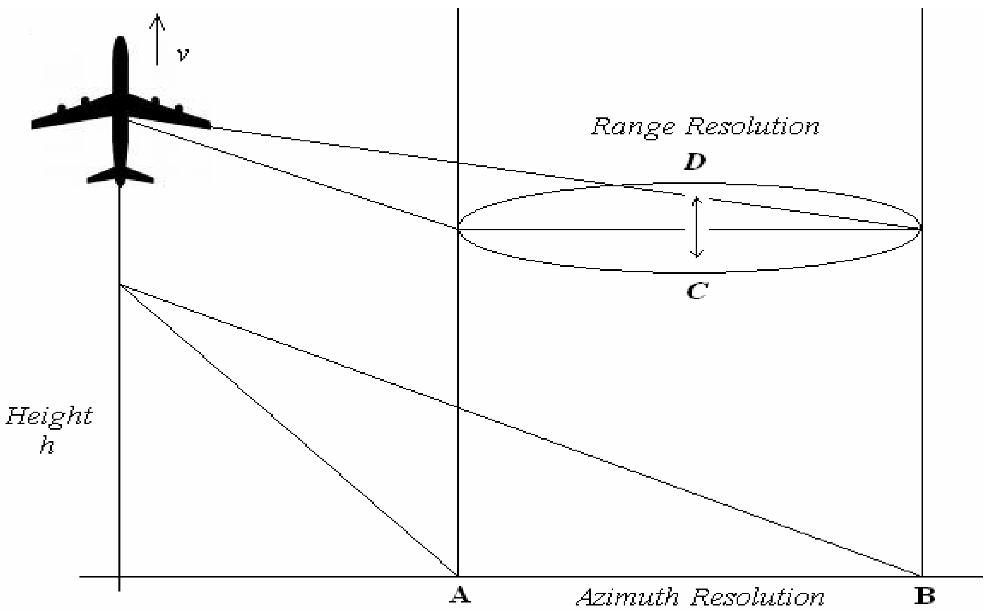

Figure 3.8: Radar footprint on the ground and cross section.

Beam width is θ

$$\theta = \lambda / L \qquad (3.1)$$ [1]

The maximum array length in figure 3.8 is *AB*. So the synthesized array will have a beam width

$$\theta_s = \lambda / AB = L/2h \qquad (3.2)$$ [1]

Rearranging equation 3.2, the resulting footprint on the ground is $\theta_s h = L/2$. The azimuth resolution X_a can therefore be expressed as:

$$X_a = L/2 \qquad (3.3)$$ [1]

This is the finest resolution that can be achieved using SAR. Clearly, the smaller the antenna is, the finer the resolution will be. The azimuth resolution is independent of the distance from sensor to target. [1]

Doppler Synthesis Approach

The radar sensor is moving with velocity *v*, the antenna has length *L* and is operating at frequency *f*. The sensor is at height *h*.

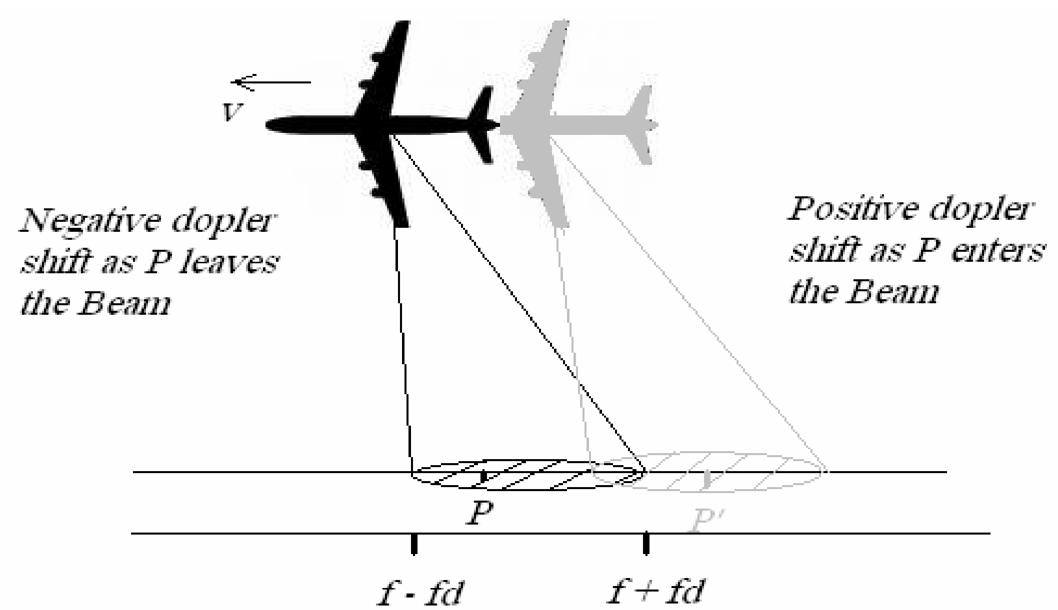

Figure 3.9: Doppler effects over a certain point on the ground.

The spectrum for the echo of P must cover at least two times the Doppler frequency, $2f_d$.

$$f_d \approx v/L \qquad (3.4)$$ [1]

If a neighbouring target P' is displaced from P by the azimuth resolution X_a, the Doppler history for P' will be a replica of that for P only displaced by t_m.

$$t_m = X_a/v \qquad (3.5)$$ [1]

The shortest time delay for a signal with Band width $B_d = 2f_d$,

$$t = 1/B_d = 1/2f_d = L/2v \quad (3.6)$$ [1]

Therefore the finest azimuth resolution X_a is,

$$X_a = vt = L/2 \quad (3.7)$$ [1]

This is the same result that was achieved with the synthetic array approach.

The resolution of the SAR does not depend on the altitude of the sensor. The imaging apparatus uses the Doppler shift in the echoes and the time delays between the points on the ground to determine the size of the pixels. Neither of these depends on the height of the sensor. [1]

3.5.1 Range Resolution

Range resolution R is determined from the time T, which it takes the radar signal to travel from the sensor to the ground and back again. The Signal travels at the speed of light c.

$$T = 2R/c \quad (3.8)$$ [1]

$$R = (c/2B) \sin\theta \ (\theta \text{ is the incident angle}) \quad (3.9)$$ [1]

Pulse width t is a function of the Band width of the transmitter. PRF must be high enough to ensure that the spectrum is adequately sampled. If the information is under sampled it can’t be processed correctly. [1]

3.5.2 Dynamic Range

Dynamic range is a ratio of the maximum measurable radar echoes to minimum measurable radar echoes within a scene. An SAR system is able to differentiate up to 100 thousand different intensity levels. Our eye can only differentiate between 40 intensity levels. Because of the wide range, decibels are used to measure the dynamic range. This is expressed in equation 3.10 below. [2]

$$dB = 10 \log (I_{max}/I_{min}) \quad (3.10)$$ [2]

3.5.3 Speckle

Speckle is a form of image noise. With the coherent detection of SAR, back scattered energy can combine and result in random constructive and destructive interference. When the random anomalies are averaged out over one pixel, it creates a random intensity pattern of light and dark patches on the image known as speckle. [2]

3.6 SAR SYSTEM DESIGN

An SAR System in its simplest form is made up of five elements; signal generation, the Antenna, signal reception, data handling and data processing. [1] This is illustrated in the block diagram below.

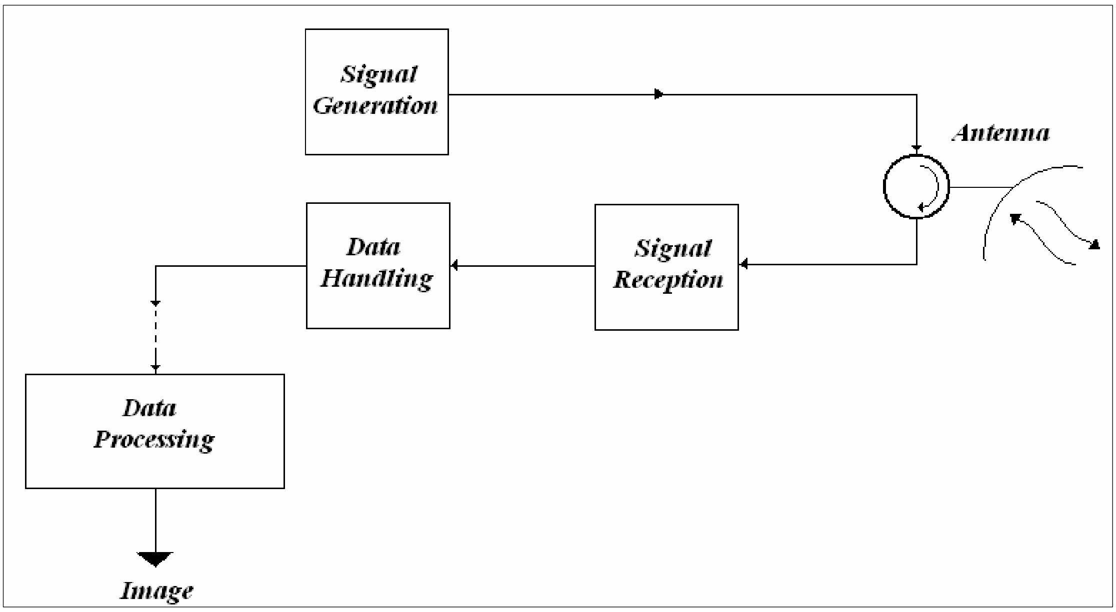

Figure 3.10: SAR System Block Diagram

3.6.1 SIGNAL GENERATION CHAIN

Mixers are used to create High frequency signal from a low frequency signal by means of up conversion. Mixers are non linear devices and produce many higher order harmonics giving the radar designer a broad range of frequencies to choose from. The desired harmonic can be isolated by using appropriate filters.

The signal parameters must be chosen accordingly. These include Frequency, PRF, Bandwidth and Power. Certain tradeoffs must be made when selecting the parameters. [1]

3.6.2 ANTENNA

The antenna has a number of characteristics. These characteristics determine the shape, gain and width of the beam. The antenna receives the backscattered energy and translates it into a signal which is sent to the sensor. The characteristics of the antenna will establish the amount of energy that can be received and from which direction it can be received. [1]

3.6.3 SIGNAL RECEPTION

The received signal must be amplified and down converted to the original low frequency. The signal is then digitized.

3.6.4 Data processing

The essence of data processing is to overcome distortion and enhance the patterns and variations. There are many causes of data distortion such as Altitude errors, earth rotation, range curvature and Depth of focus.

Altitude errors may occur if the aircraft that the sensor is installed on had to pitch or roll from its ideal altitude. Some of these errors can be measured and compensated for. [1]

Earth Rotation can result in undesirable Doppler shifts especially around the equator. Here the shift may me larger than the Doppler spread of the azimuth beam width which is used in generating the SAR. [1]

Range curvature can be defined as the change in range between the sensor and the target while the synthetic aperture is being created. If the change in range is larger than the slant range resolution, the processor must then compensate. [1]

Depth of focus describes a range of targets that use the same reference function to focus them. The range curvature for the targets in this range does not vary by more than a quarter of the wavelength. The ratio of swath width to depth of focus is equal to the number of reference functions needed to create the synthetic aperture.

4 SAR IMAGE PROCESSING TECHNIQUES

All image processing was performed at the CSIR by Minette Lubbe. Two techniques were used, namely Principal Component Analysis (PCA) and Image Fusion (IF).

4.1 PRINCIPAL COMPONENT ANALYSIS

4.1.1 DEFINITION

PCA is a linear transformation. It transforms an original data set onto a new co-ordinate system. The transform is derived from the covariance matrix of the original data set. The new co-ordinate system has principal component axes. In order to transform the original data set onto the PC Axes we need the Eigen values and Eigen vectors. They are obtained from the covariance matrix and used as the coefficients in the transformation. The highest Eigen value is the most significant. It represents the highest variance which in turn indicates that it contains the most information about the original data. In PCA variance equates to information. The highest Eigen value will result in the first principal component, the second highest in the second principal component and so forth.

By plotting the Eigen vectors you can recognize distinct patterns within the data. Almost all of the information (99%) about the data is contained in the first four Eigen vectors also known as bands. Each band can be represented in a different colour. The bands are often easier to interoperate than the original data as patterns are, to a large extent, enhanced.

PCA has a number of advantages. At allows the compression of data with minimal loss of information. It can be applied for enhancement to allow for pattern recognition especially useful when classifying ground cover. [3] [4] [6]

4.1.2 METHOD

- Collect data in the form of SAR images.
- Subtract the mean - Create a data set that has a zero mean by subtracting the mean from each data dimension.
- Calculate the Covariance Matrix.
- Obtain the Eigen values and Eigen vectors from the Covariance Matrix.
- Choose the bands that best characterize the data and have minimal loss of information. Usually the low order components. The highest Eigen value being the lowest order component.
- Derive the new data set – use the Eigen values as the coefficients for the transform to map each component of the input data.

4.1.3 APPLICATION

SASAR VHF

In my case the first four bands where chosen. False Colour composite images can be formed by combing any of the four principal components. Each band is assigned Red, Green or Blue resulting in an RGB image.

Table 4.1: Eigen matrix for SASAR leg 1

	Band 1	**Band 2**	**Band 3**	**Band 4**
Band 1	0.442115	-0.89391	-0.06499	-0.03526
Band 2	0.501692	0.263466	0.219911	-0.79406
Band 3	0.61544	0.248018	0.451863	0.596272
Band 4	0.417221	0.264584	-0.86211	0.112633

These are the coefficients used to transform the original data.

Table 4.2: Eigen Values for SASAR leg 1

Bands	**Eigen values**	**Percentage**
Band 1	3516.93	77.2
Band 2	453.73	9.9
Band 3	396.62	8.7
Band 4	190.32	4.2
Total	4557.6	100

These Values reflect the amount of information contained in each band. It is clear from these figures that most of the information is contained in the first principal component and there is very little information in the Fourth principal component. The Fourth component is mostly noise as can be seen in Figure 4.4 below.

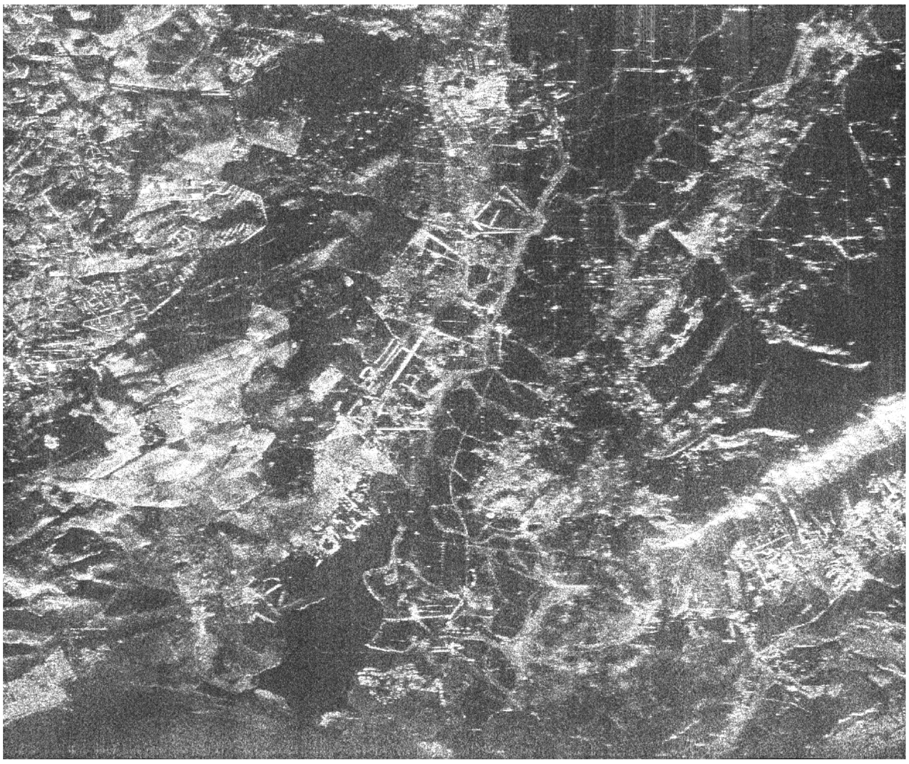

Figure 4.1: First Principal Component of SASAR VHF leg 1.

This Band contains the most information about the original data and closely resembles black and white optical image.

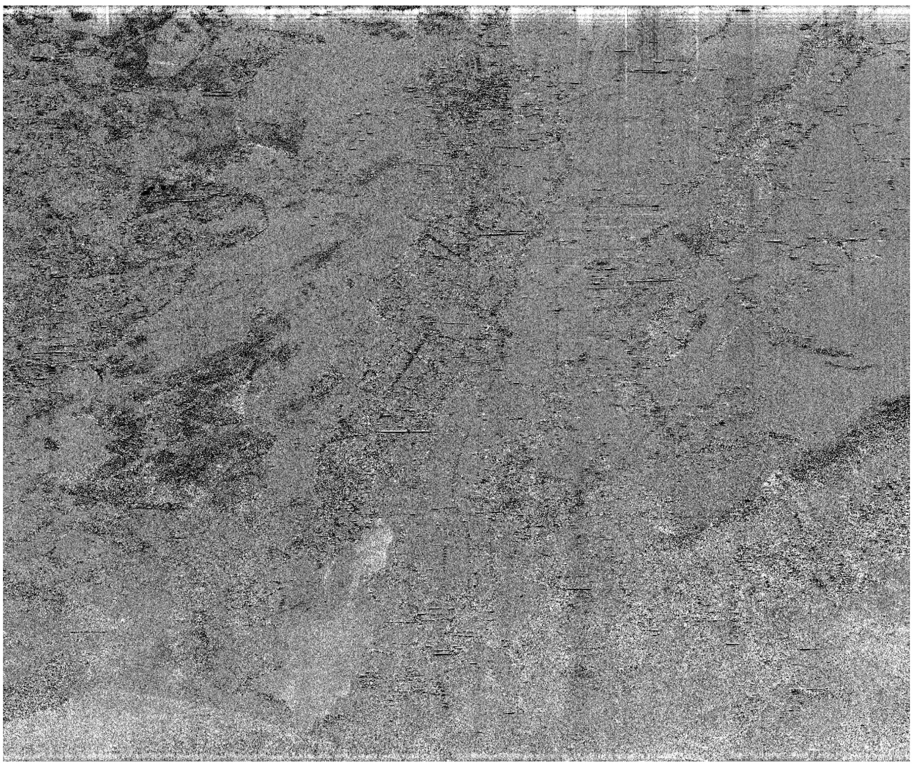

Figure 4.2: Second Principal Component of SASAR VHF leg

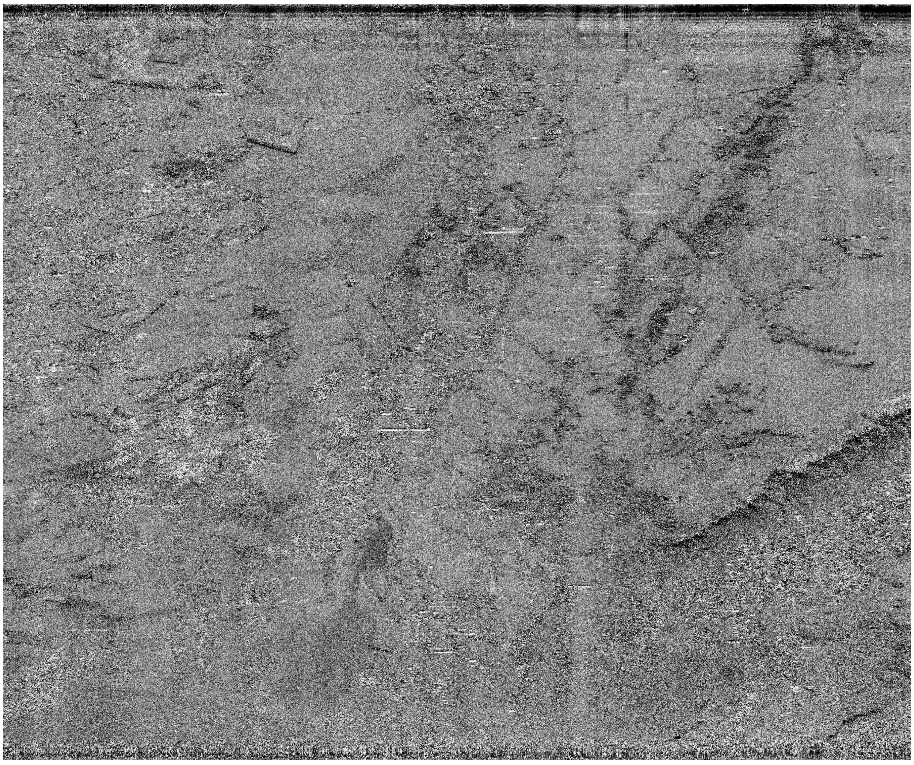

Figure 4.3: Third Principal Component of SASAR VHF leg 1

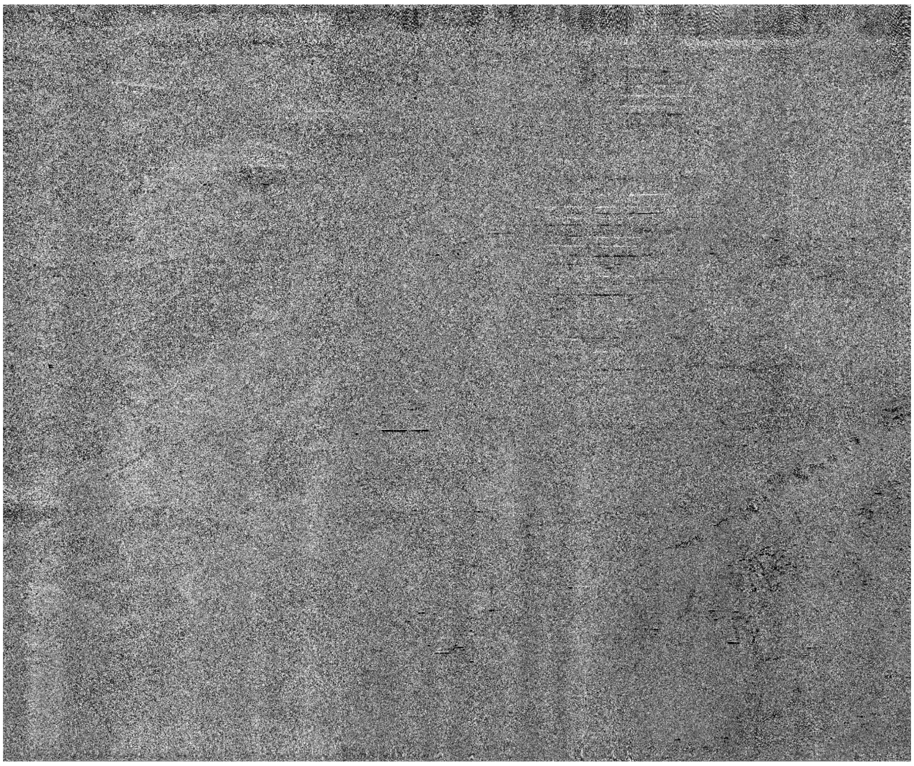

Figure 4.4: Fourth Principal Component of SASAR VHF leg 1

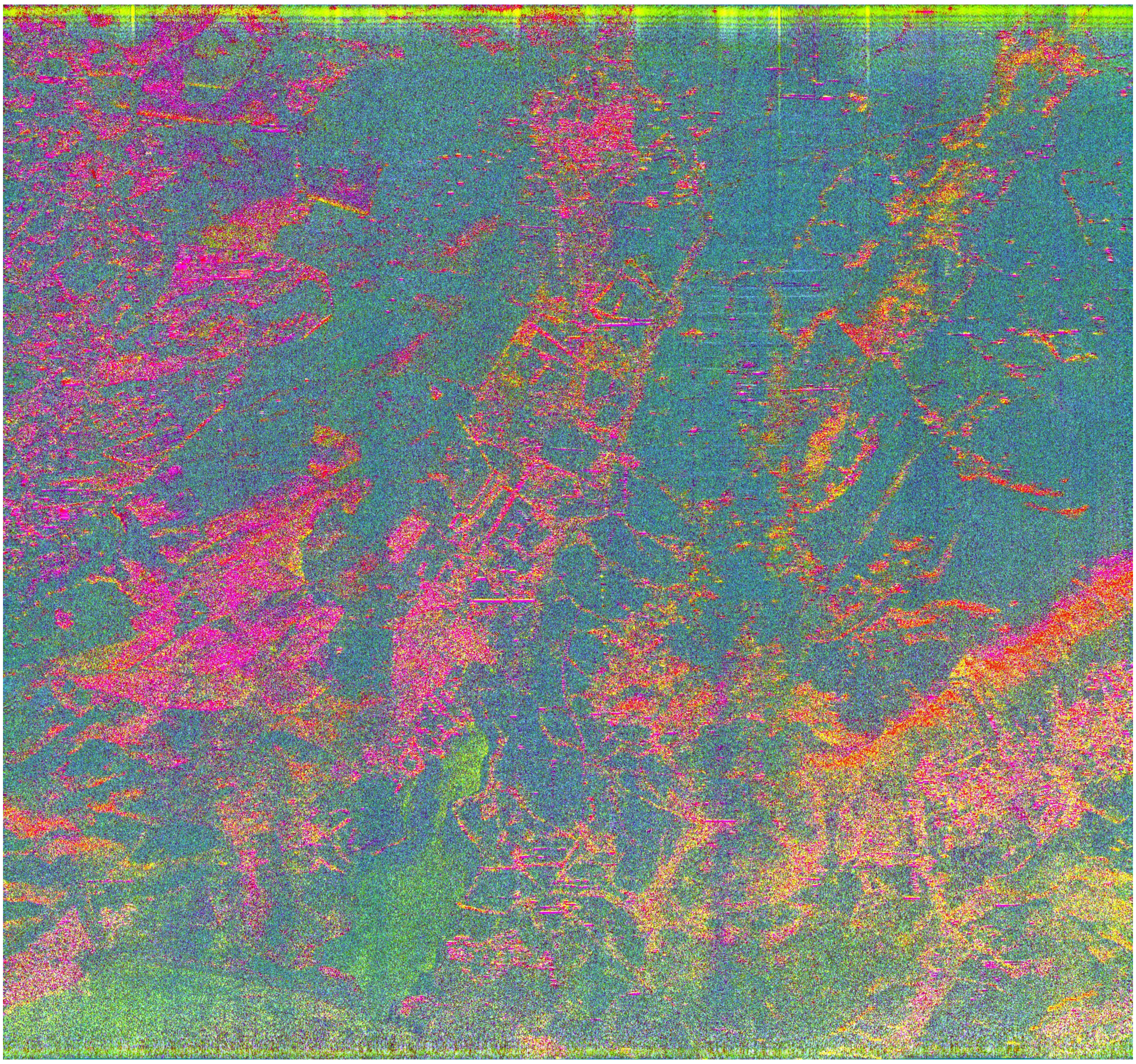

Figure 4.5: First, Second and Third Principal Components of SASAR VHF combined to form False Colour Composite.

ERS Data

The following figures show the first Three Principal Components of the ERS data.

Figure 4.6: First Principal Component of ERS Data

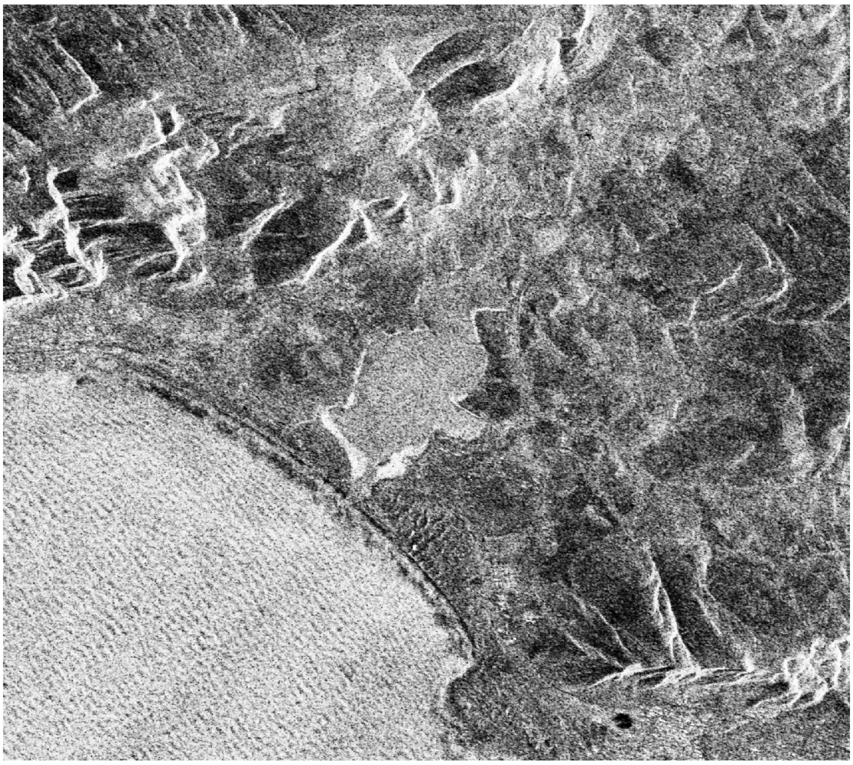

Figure 4.7: Second Principal Component of ERS Data

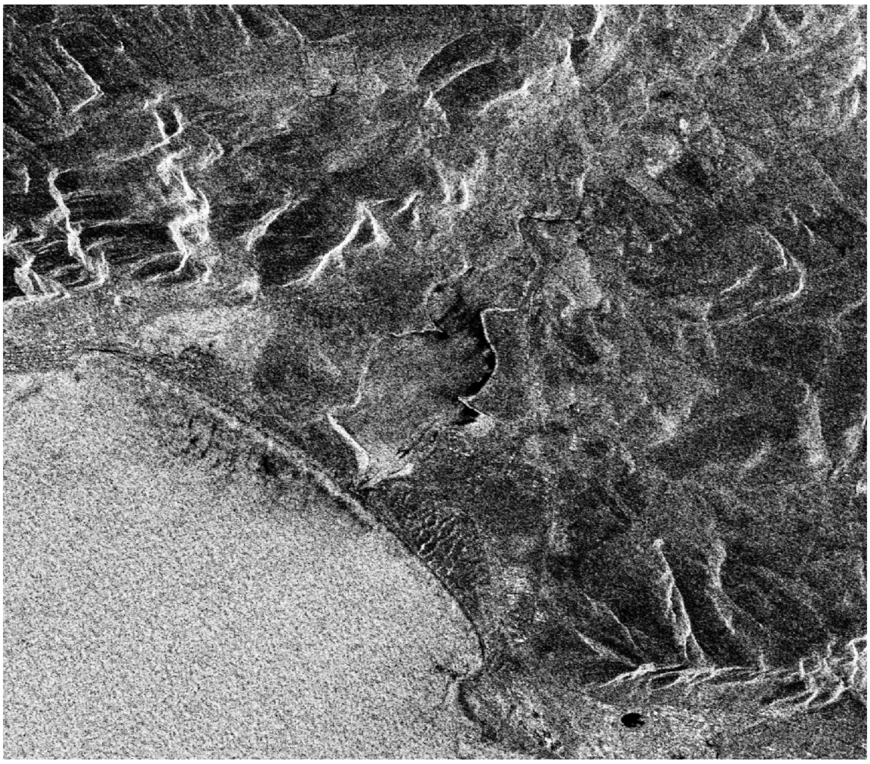

Figure 4.8: Third Principal component of ERS Data

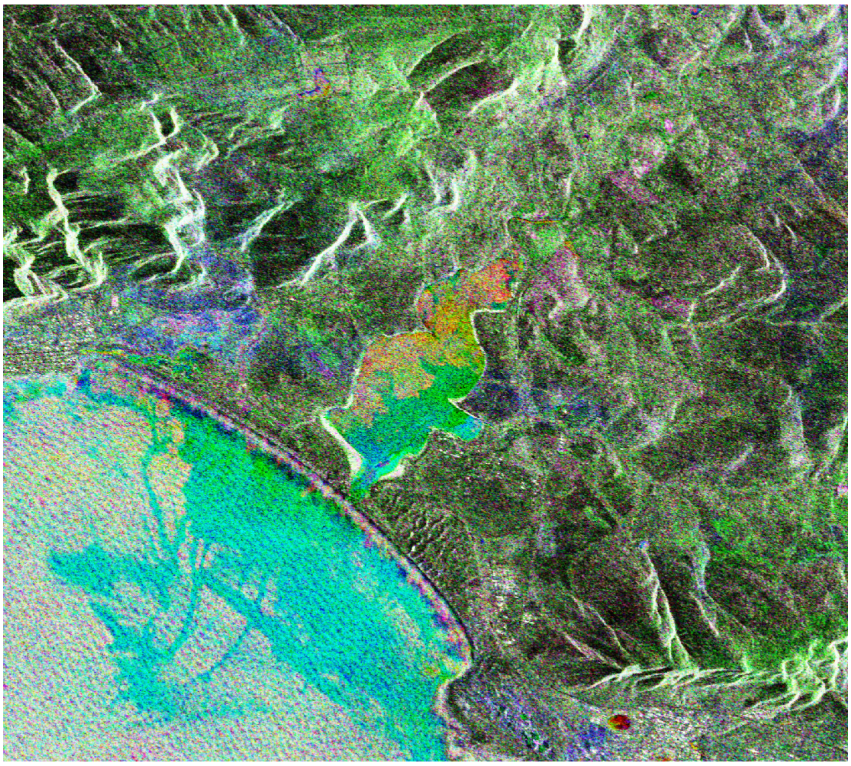

Figure 4.9: First, Second and Third Principal Components of ERS data combined to form a False Colour Composite

4.2 Image Fusion

4.2.1 Background

Remote sensing is a fast growing industry. There is a continuous need for higher spectral and special resolution SAR images. One way to achieve this is to construct new satellites that have the technology to capture exceedingly resolved information. An alternative and more economic solution is to utilize the image processing techniques that are already available, such as Image Fusion.

The purpose of IF is to combine multi spectral images of low resolution with a high resolution optical image. This process will assist image analysis. We want to preserve spectral information as it is required for routines such as vegetation study.

Multi source image fusion is an intricate process. There are numerous techniques all making use of complex transformations. In this report I will discuss the techniques used by Minette Lubbe at the CSIR. Those are Standardised Principal Component (SPC) Transformation and Intensity, Hue and Saturation (IHS) Transformation. [3] [5]

4.2.2 Intensity, Hue and Saturation Transformation

The IHS system can separate an image into three different channels each showing a different colour characteristic; intensity, hue and saturation. This colour spectrum is advantageous as the eye sees these three characteristics on a nearly orthogonal perceptual axis.
IHS fusion follows three important steps:

- Use a forward transformation to map an RGB onto an IHS axis.
- Replace the intensity channel with the high resolution optical image. The intensity shows the brightness of an image and is in many ways similar to the optical photo.
- Transform the modified image back to RGB format. [3] [5]

SASAR VHF Data
SASAR VHF

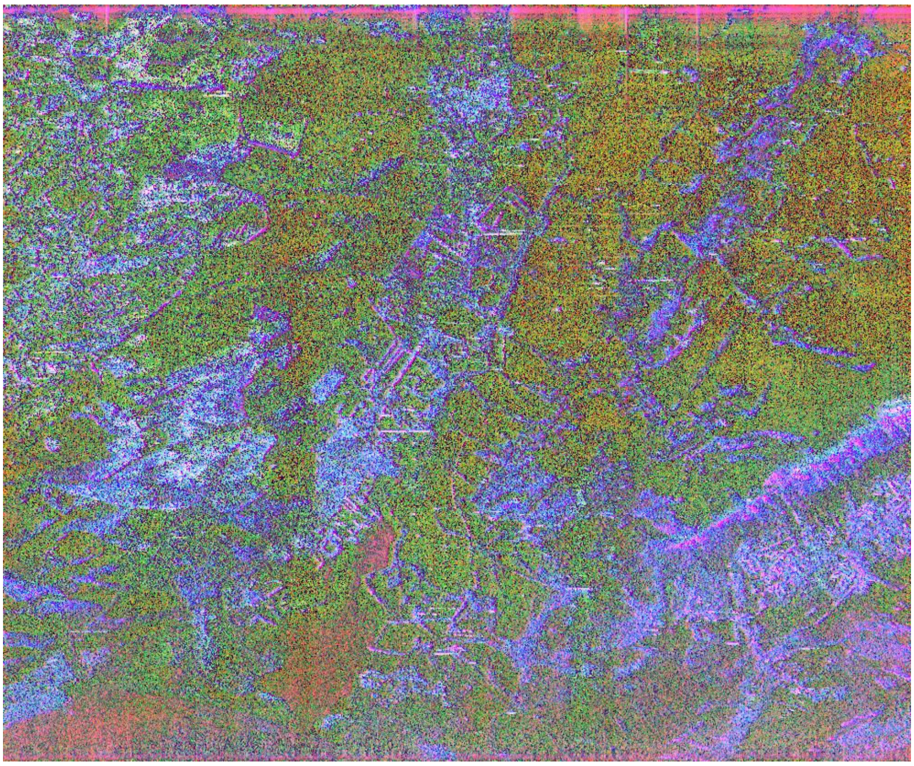

Figure 4.10: Intensity, Hue and Saturation for SASAR VHF leg 1

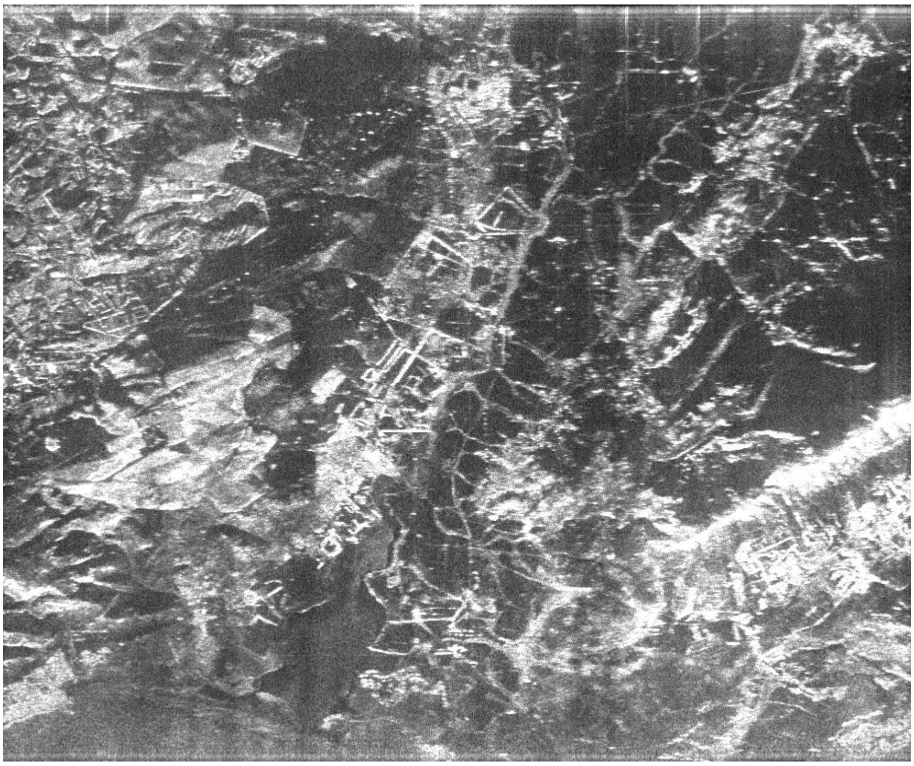

Figure 4.11: Intensity layer for SASAR leg 1

The Intensity layer, like the first principal component, resembles a black and white optical photo.

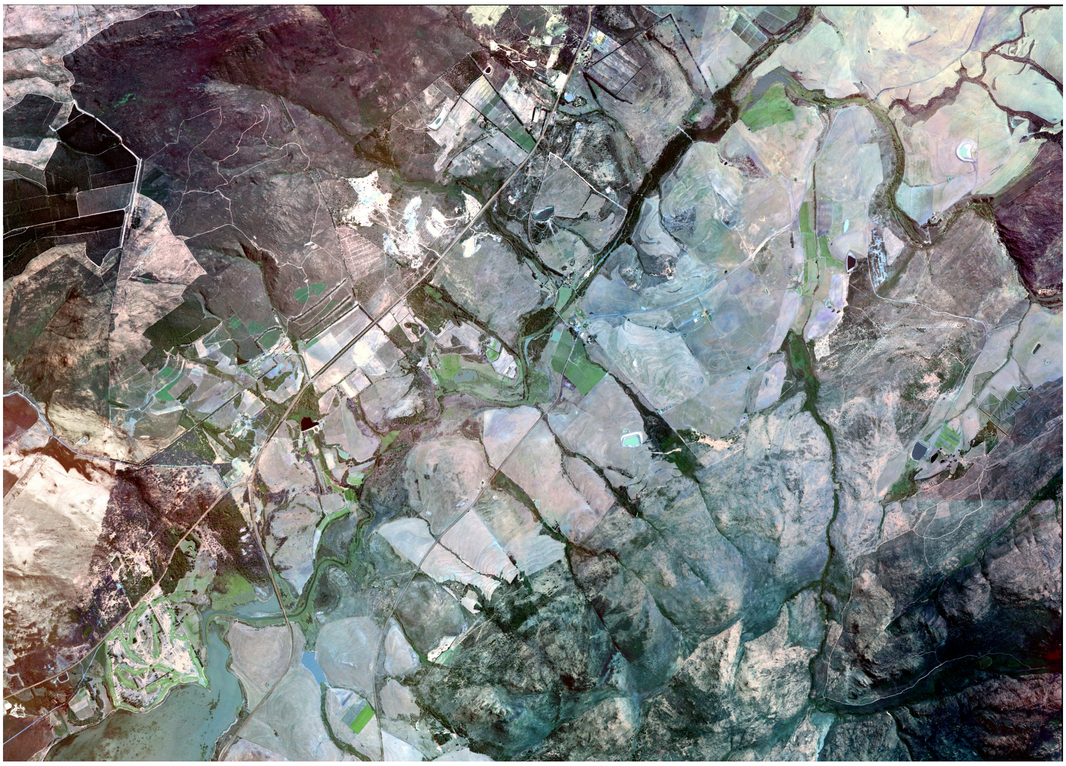

Figure 4.12: High resolution Optical photo to be fused with SASAR IHS image.

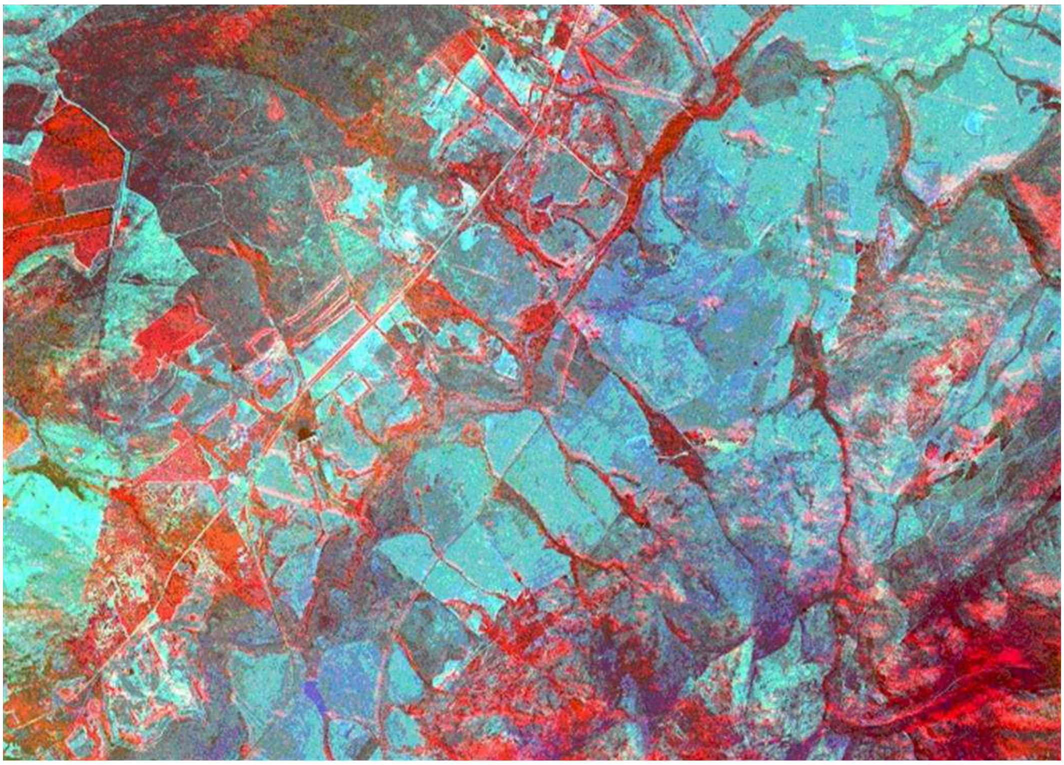

Figure 4.13: Intensity layer of SASAR VHF replaced by high resolution optical image.

ERS Data

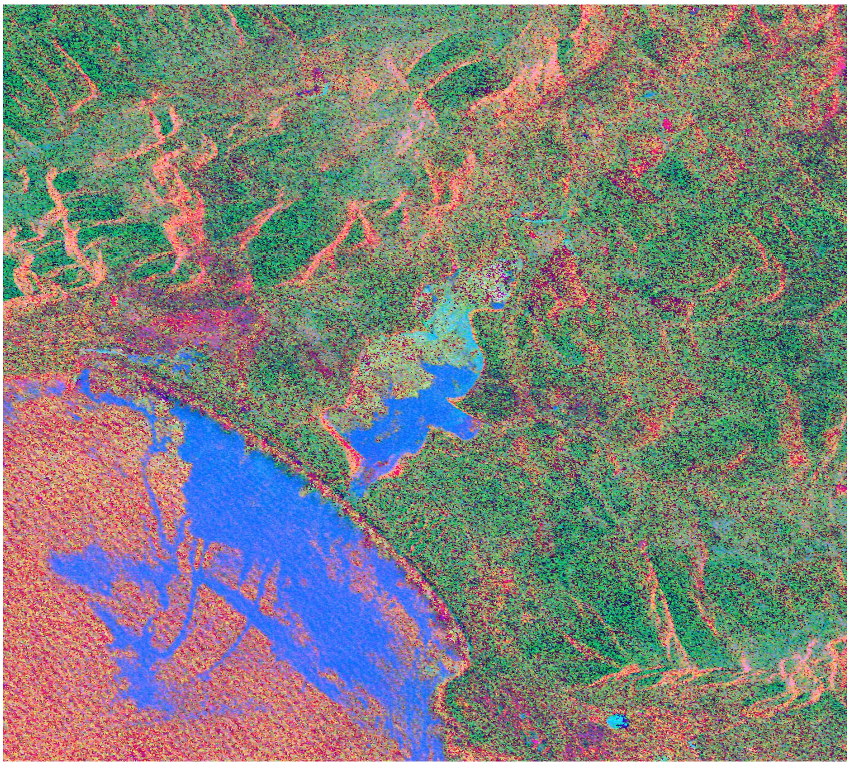

Figure 4.14: Intensity, Hue and Saturation transform of ERS Data

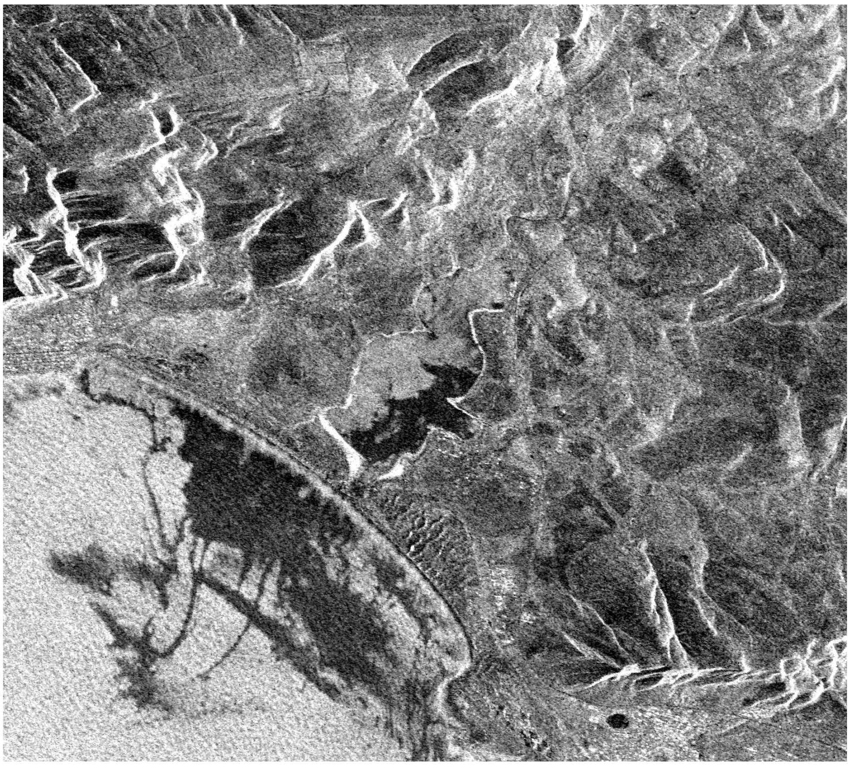

Figure 4.15 Intensity layer of ERS Data

Notice once again how the intensity layer resembles the black and white photography of the region.

4.2.3 Standardised Principal Component Transformation

SPC transform differs from the PC transform in three ways:

- The correlation matrix is used to find the transform function instead of the covariance matrix.
- All principal component bands are of equal importance.
- The infrared band is replaced by the optical photo as it shows greater levels of variance as appose to the first principal component. [3] [5]

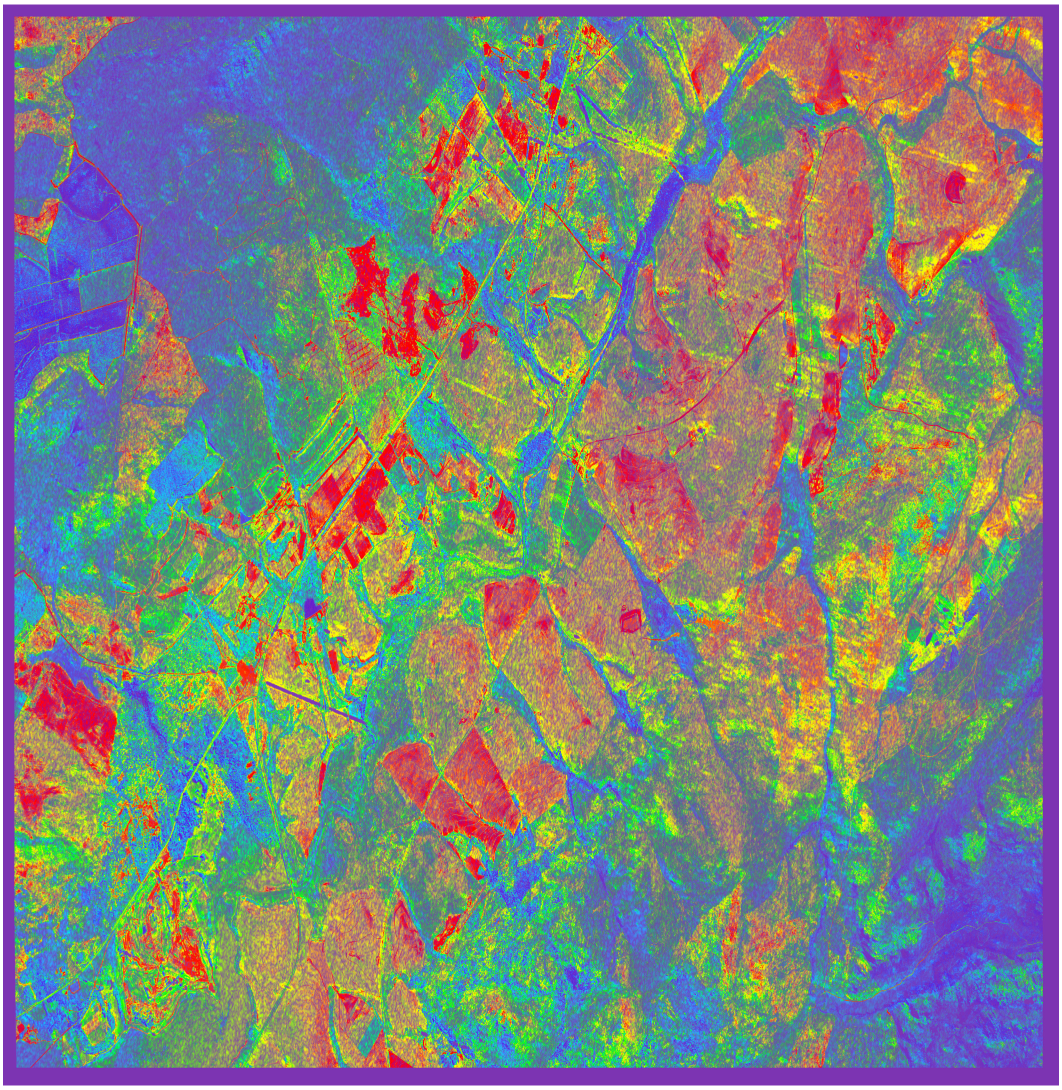

Figure 4.16: SPCT Image fusion of optical photo with SASAR data.

5 INTERPRETATIONS AND COMPARISON

In this section of the report I will look at individual features in the radar images and compare them to the optical images to clarify what the features represent. I will look particularly at sections of the image that have a strong return relative to the surrounding area. Using ERDAS imaging software I am able to link the radar image with the Optical image so I can see the object that is causing a strong return.

I have classified the identified features into Man made objects; buildings, urban areas, roads and power lines, and Natural features; vegetation, water bodies and relief.

At the end of the analysis I will be able to determine which of the radar sensors is best suited for any feature of the landscape, man made or natural.

The images used in this analysis are; optical images obtained from the Department of Surveys and Mapping and Google Earth, a SASAR VHF and an ERS image.

The SASAR VHF image is made up of four layers. Each layer has different polarization, HH, VH, HV, VV. The layers are overlaid to create a False Colour Composite (FCC).

The ERS image is a False Colour Composite made up of three layers which are the first three principal components.

Figure 5.1: Google Optical Image

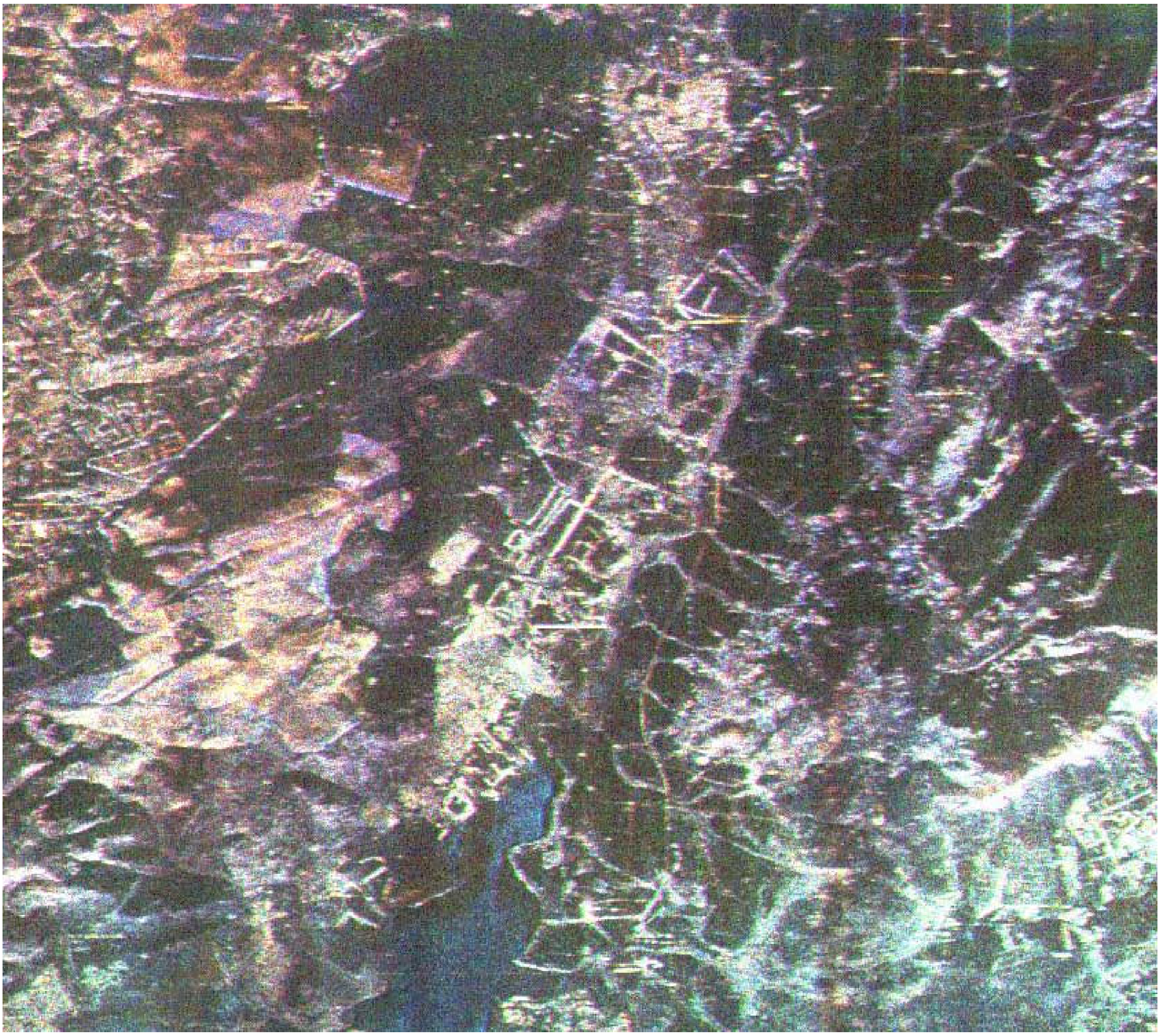

Figure 5.2: SASAR VHF False Colour Composite

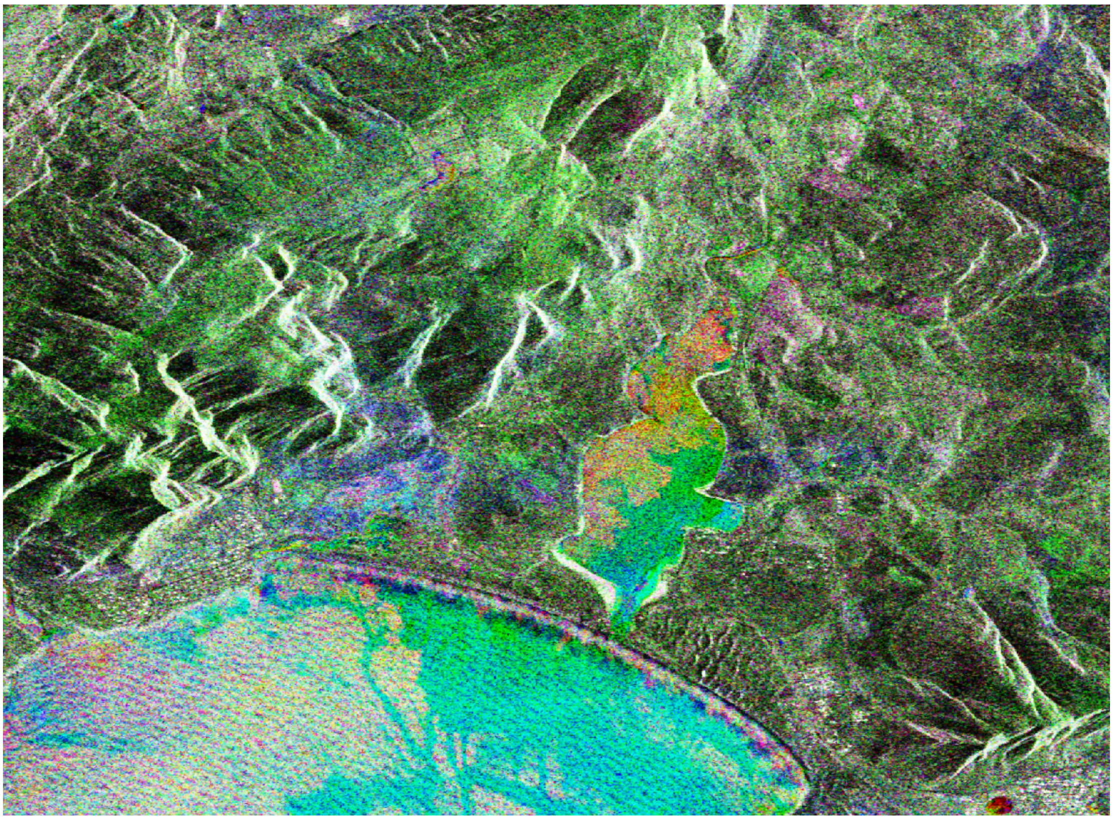

Figure 5.3: ERS False Colour Composite

5.1 MAN MADE FEATURES

5.1.1 BUILDINGS

Individual

Figure 5.4 shows how an individual building can be detected by the SASAR radar sensor. This particular building could not be seen by the ERS sensor. A possible reason for such a strong return from this building is its uniform shape. The building can be modelled as a point target.
It is still difficult to differentiate between an individual building and other elevated objects such as a large tree or small steep hill such as a koppie.

Figure 5.4: Individual Building

Cluster

Figure 5.5 is an example of a small cluster of buildings.

Figure 5.5: A small cluster of buildings

5.1.2 Urban Areas

Kleinmond

Kleinmond is a small development on the western bank of the Bot Rivier estuary.

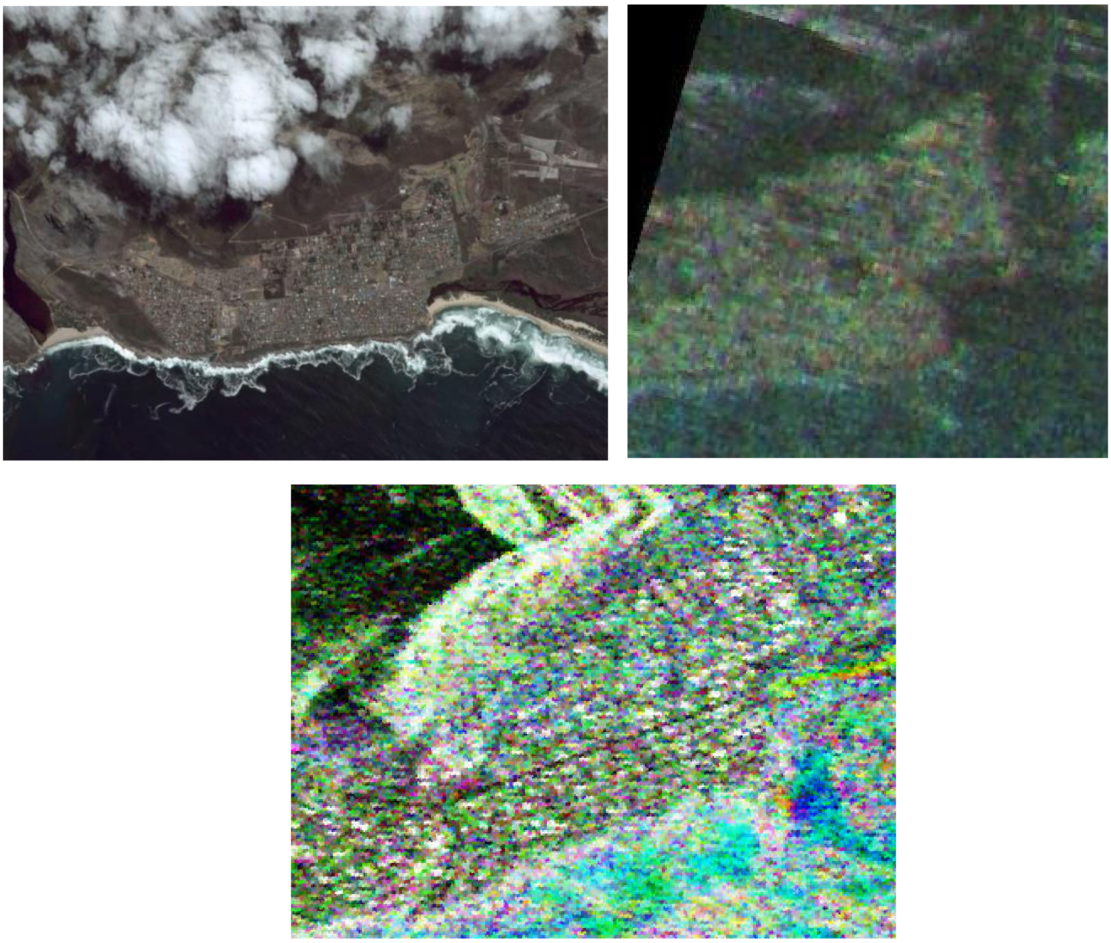

Figure5.6: Urban area of Kleinmond. Clockwise from the top left corner: Optical, SASAR VHF, ERS.

Hawston

Hawston is a small urbanized area on the eastern shore of the Bot Rivier Estuary.

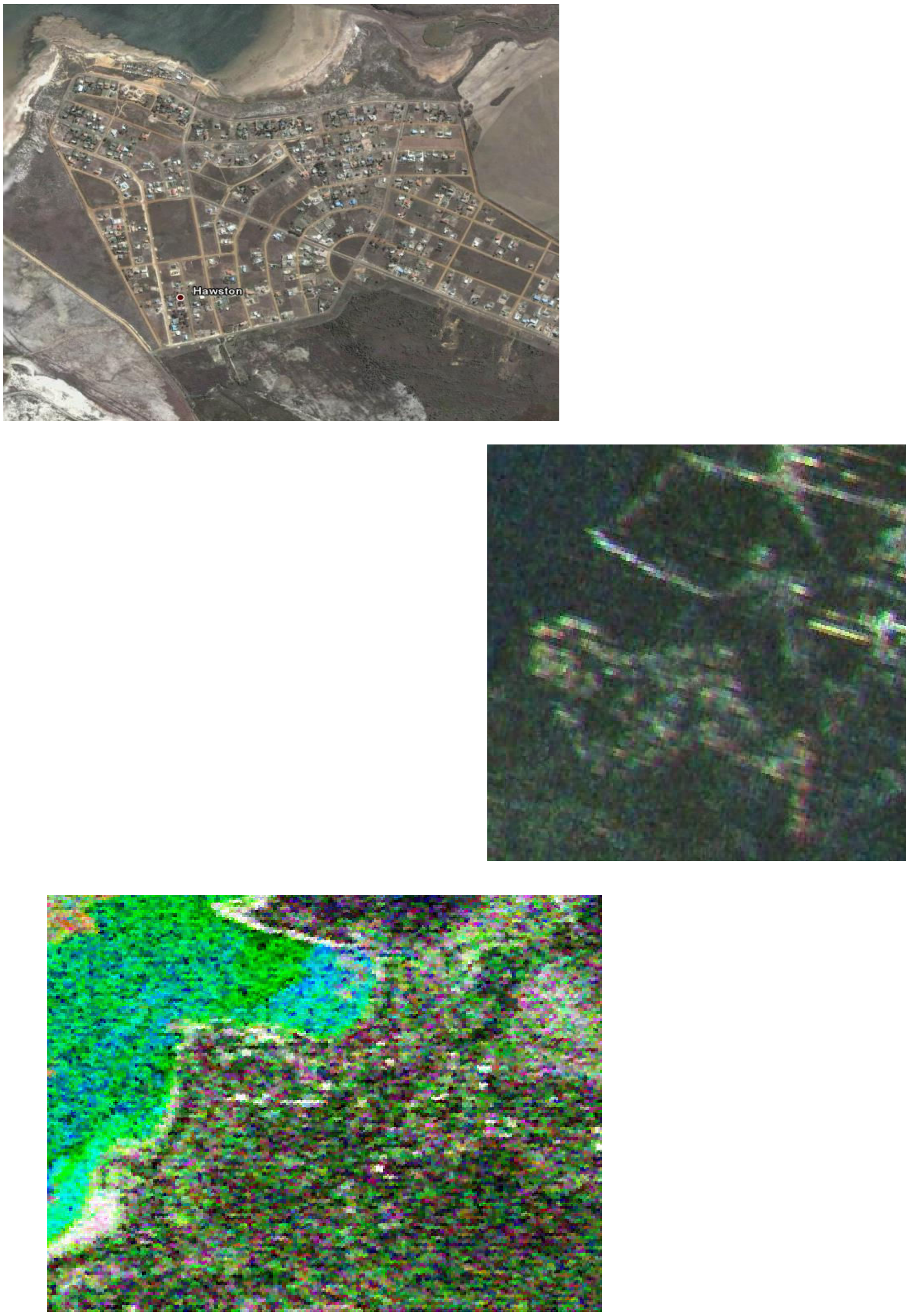

Figure 5.7: Urban area of Hawston. Clockwise from the top left corner: Optical, SASAR VHF, ERS. The ERS image does not have as good a representation of the urban area compared to the SASAR image.

Bot Rivier

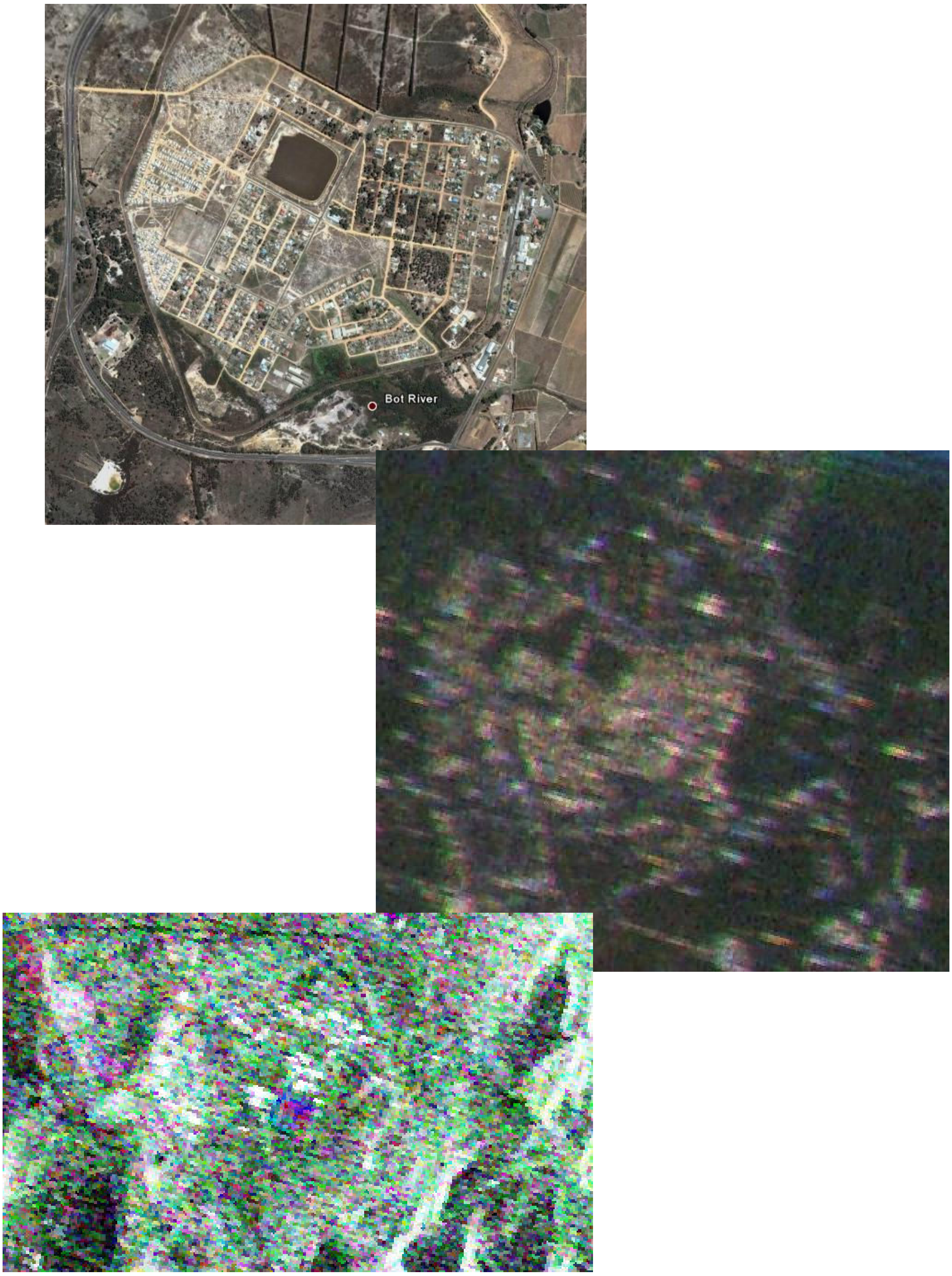

Figure 5.8: Bot Rivier. Clockwise from top left corner, Optical, SASAR VHF, ERS

Hermanus

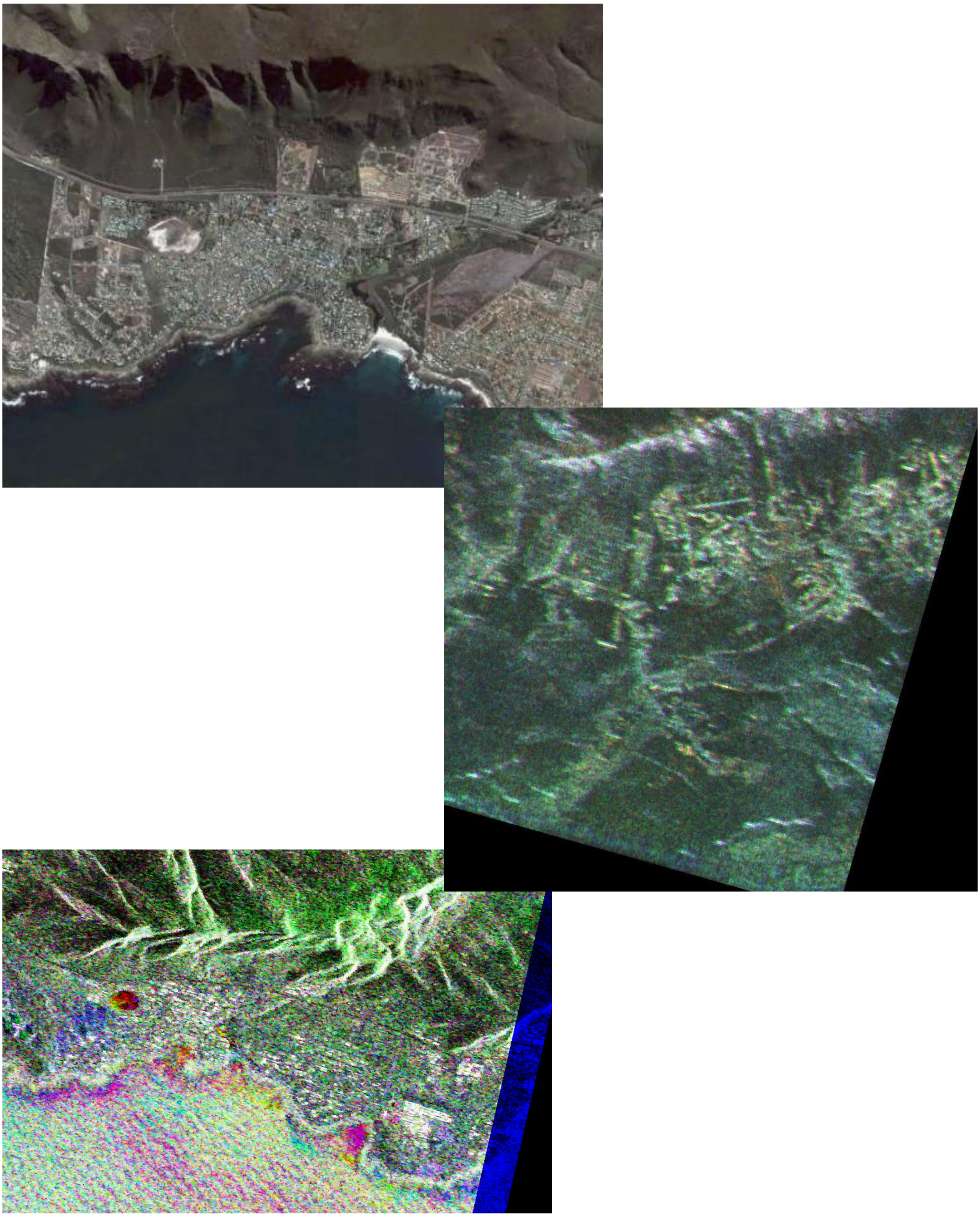

Figure 5.9: Town of Hermanus. Clock wise from top left; optical, SASAR VHF, ERS.

From looking at the four different urban areas we can say that for small urban areas, such as Hawston and Bot Rivier, the ERS sensor does not give an adequate return to be able to interoperate the image correctly. There is insufficient contrast between the buildings and the surrounding areas. A more densely urbanized area is better seen by the ERS sensor as there is higher contrast for example Kleinmond and Hermanus.

The SASAR sensor gives bright returns for all four urbanized areas. However it is also clear that the returns from the Kleinmond and Hermanus areas show a higher building density.

The SASAR returns from Hawston show bright return separated by relatively large dark areas indicating a lower building density.

5.1.3 ROADS

Roads and thoroughfares are best detected by SASAR VHF when lined with trees or if they act as a boundary line between different types of vegetation. Figure 5.10 and figure 5.11 below illustrates an example of each. The ERS sensor was unable to detect roads. Bridge structures are also undetected by the sensors.

Tree lined road

Figure 5.10: Road lined by trees as seen by optical photo (left) and SASAR sensor (top right). The Road appears as a bright line diagonally across the SASAR image.

Boundary line Road

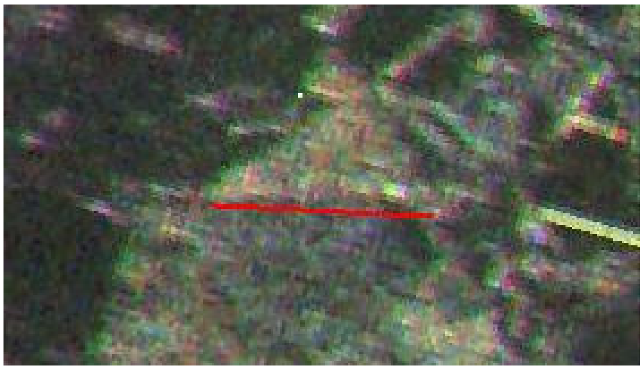

Figure 5.11: Road parallel to flight path. Optical (left), SASAR VHF (right)

If you compare the SASAR and the optical images of figure 5.11, you can see that the road acts as a barrier between two different types if vegetation. Above the road the vegetation is dense bush and trees where as below the road there is only low laying shrubs. The different density is evident in the SASAR image as well. It seems that this is the reason why this dirt road would be detected by the SASAR sensor.

Tar road

Figure 5.12: A Tar road. SASAR (left), Optical (right)

This particular road is bordered on either side by a strip of vegetation which is higher than the surrounding vegetation. This is the reason why this road gives a strong return signal relative to the surrounding area. The optical image shows how the road is elevated.

5.1.4 Power Lines

Power lines are only detectable when they are positioned parallel to the flight path. The power line catenaries appear as bright lines across the SASAR images. The power lines continue on either side of the bright stripe but are only seen by the sensor when they are perfectly parallel to the flight path. They are not detected at all by the ERS sensors.
The Power line Pylons can be detected as bright spots in the SASAR image.

The catenaries are seen best in HH polarization of the SASAR images. The SASAR images in figure 5.13 show all four layer of polarization.
Catenaries

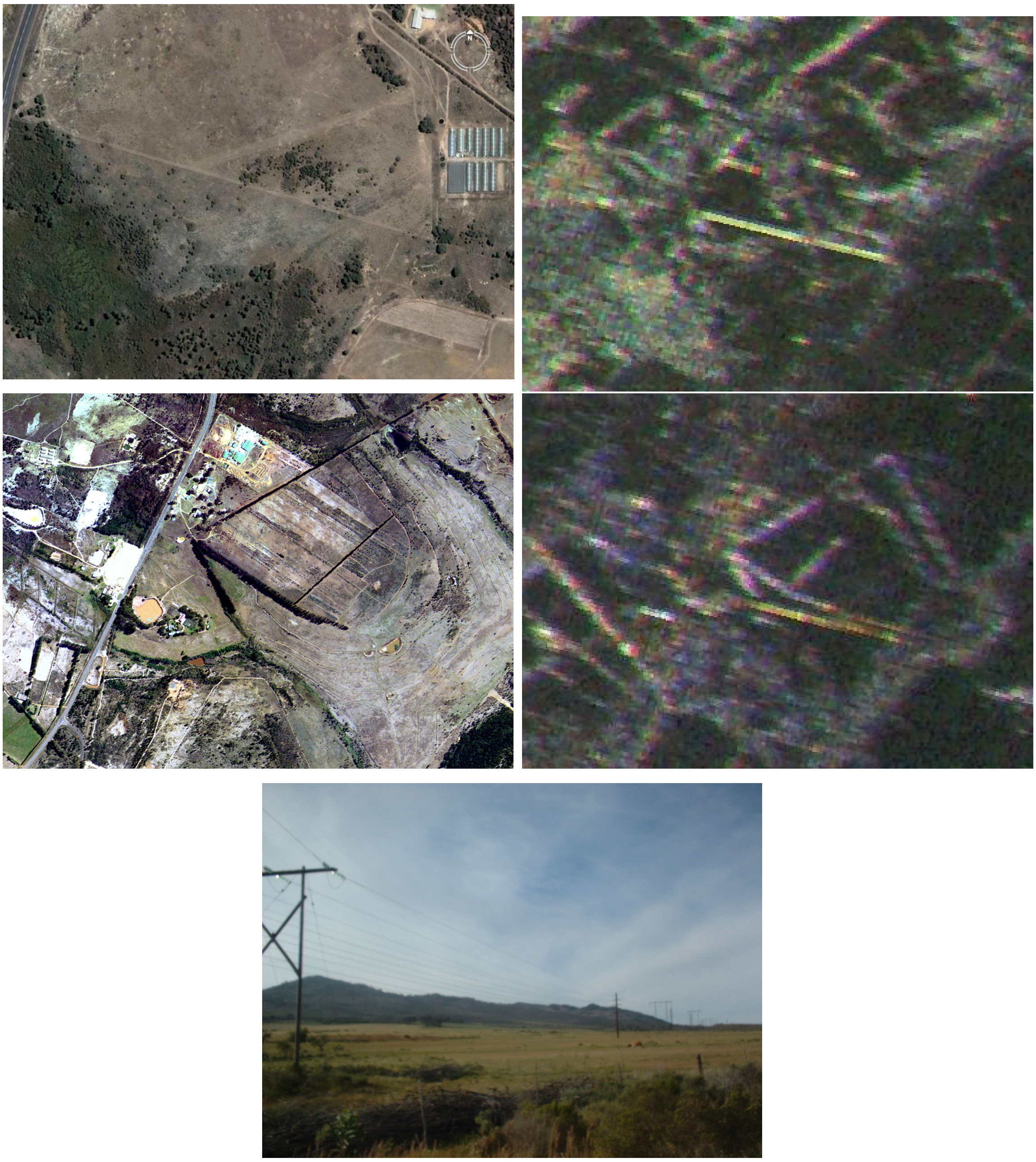

Figure 5.13: Power lines. The power line appears as a bright stripe parallel to the flight path in the SASAR image (right).

Pylons

Figure 5.14: Power line pylons west of Bot Rivier.

The pylons can be seen in the SASAR VHF image (top right, figure 5.14), as long rows of equally spaced bright spots. The pylons are almost impossible to see in the optical image (top left) without first detecting them in the SASAR image. The bottom image shows a close up of one of the pylons from the bottom row. Below in figure 5.15 there is another example of power line pylons.

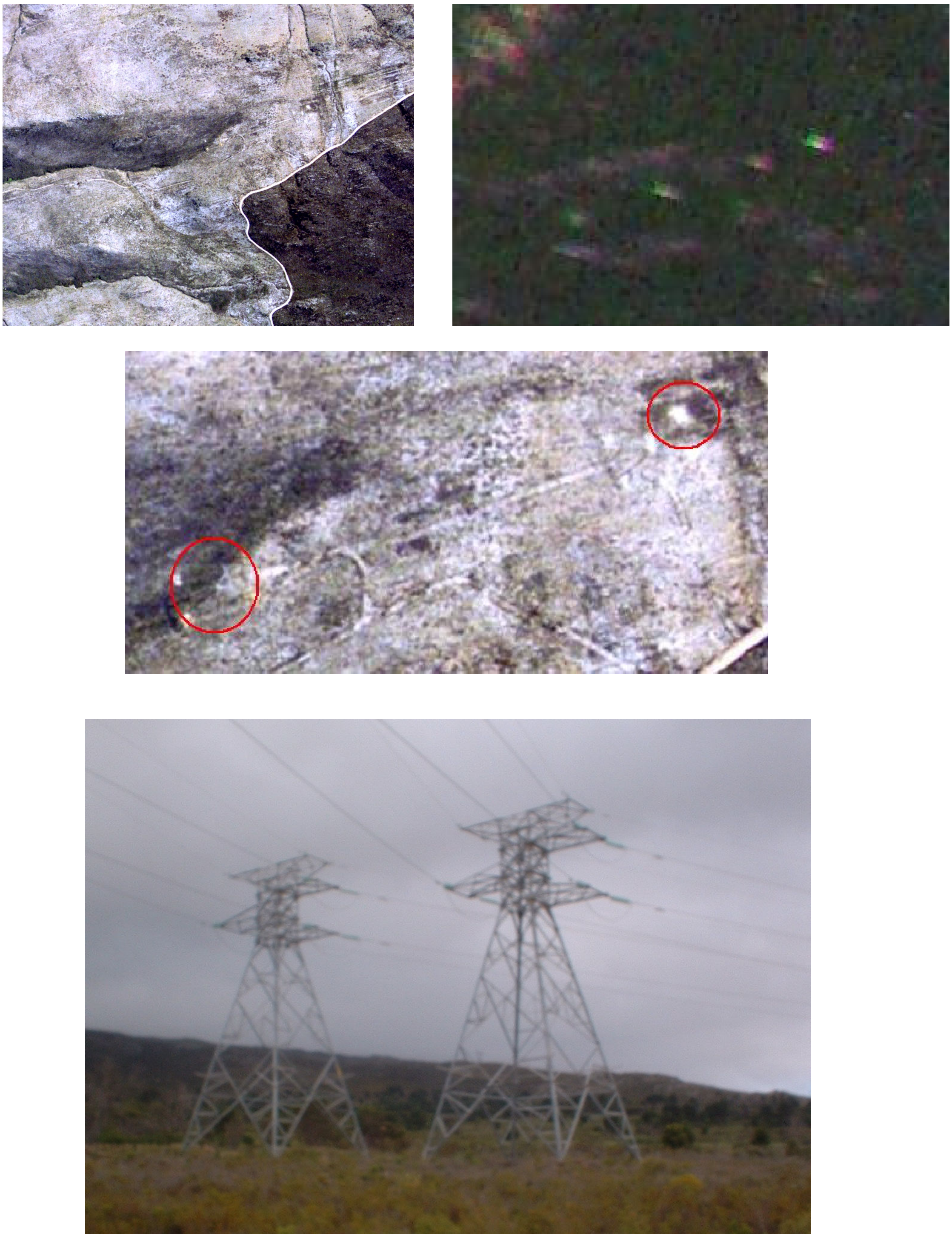

Figure 5.15: Power line pylons west of the town of Bot Rivier. Top left is an aerial optical photo, top right is the SASAR image, middle is an optical close up of the pylon, and bottom image is an example of a power line pylon.

5.2 Natural Features

5.2.1 Vegetation

The vegetation features were only visible with the SASAR VHF images. The Short wavelength of the c- band ERS sensor does not allow the radar signal to penetrate the surface ground cover. Therefore there is little difference in the ERS sensor returns from different types of ground cover. It would be impossible to determine what kind of vegetation you are looking at from the ERS images.

Tree rows

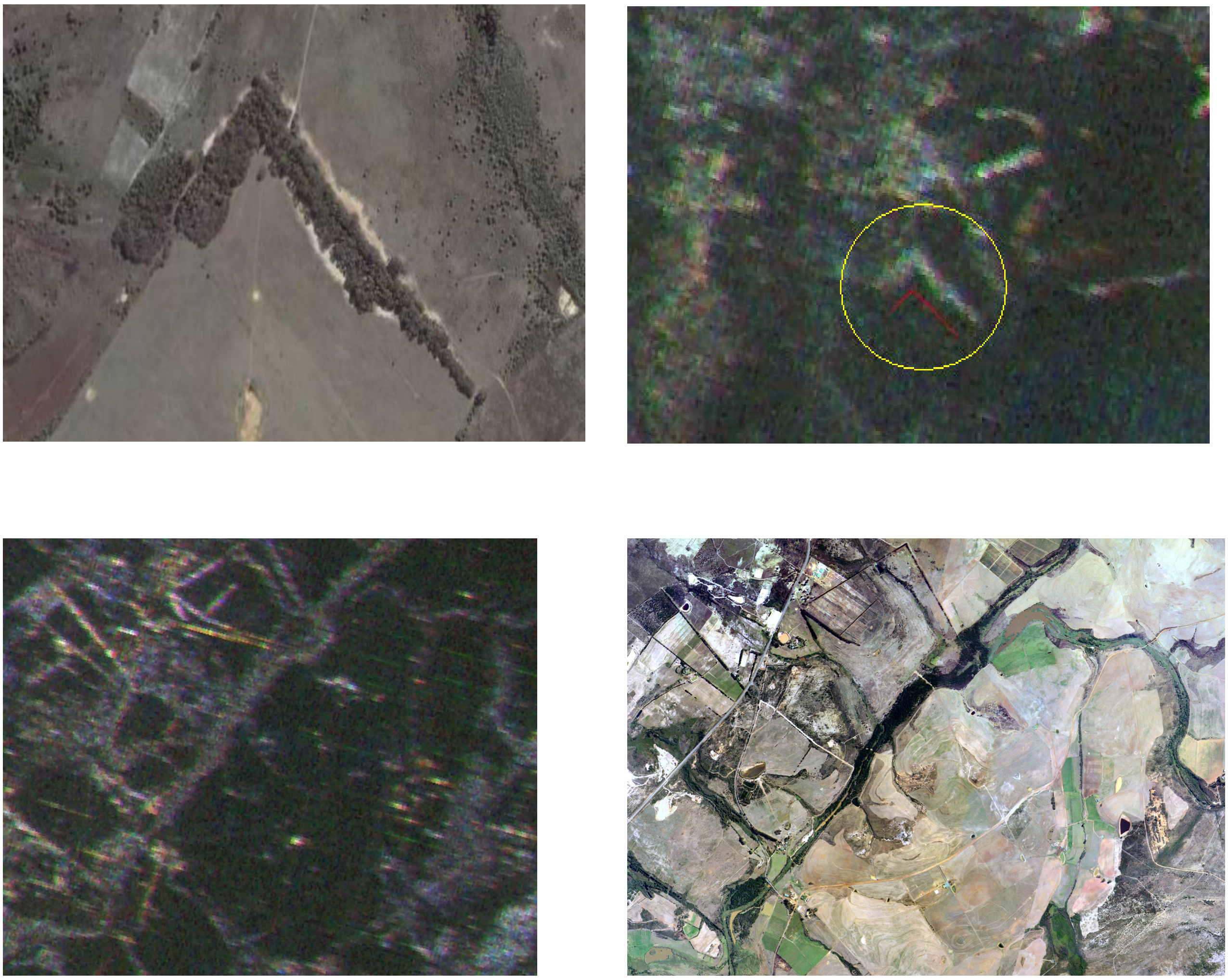

Figure 5.16: Row of trees.

The row of trees is circled in yellow on the SASAR image for clear interpretation (top right). The bottom row shows another example of a long row of trees. The shape of the row of trees is clear in the SASAR image (bottom left).

Forest

Forests and other clusters of vegetation are better detected by the SASAR sensor due to longer wavelength. This allows superior penetration of the top layer of the vegetation volume.

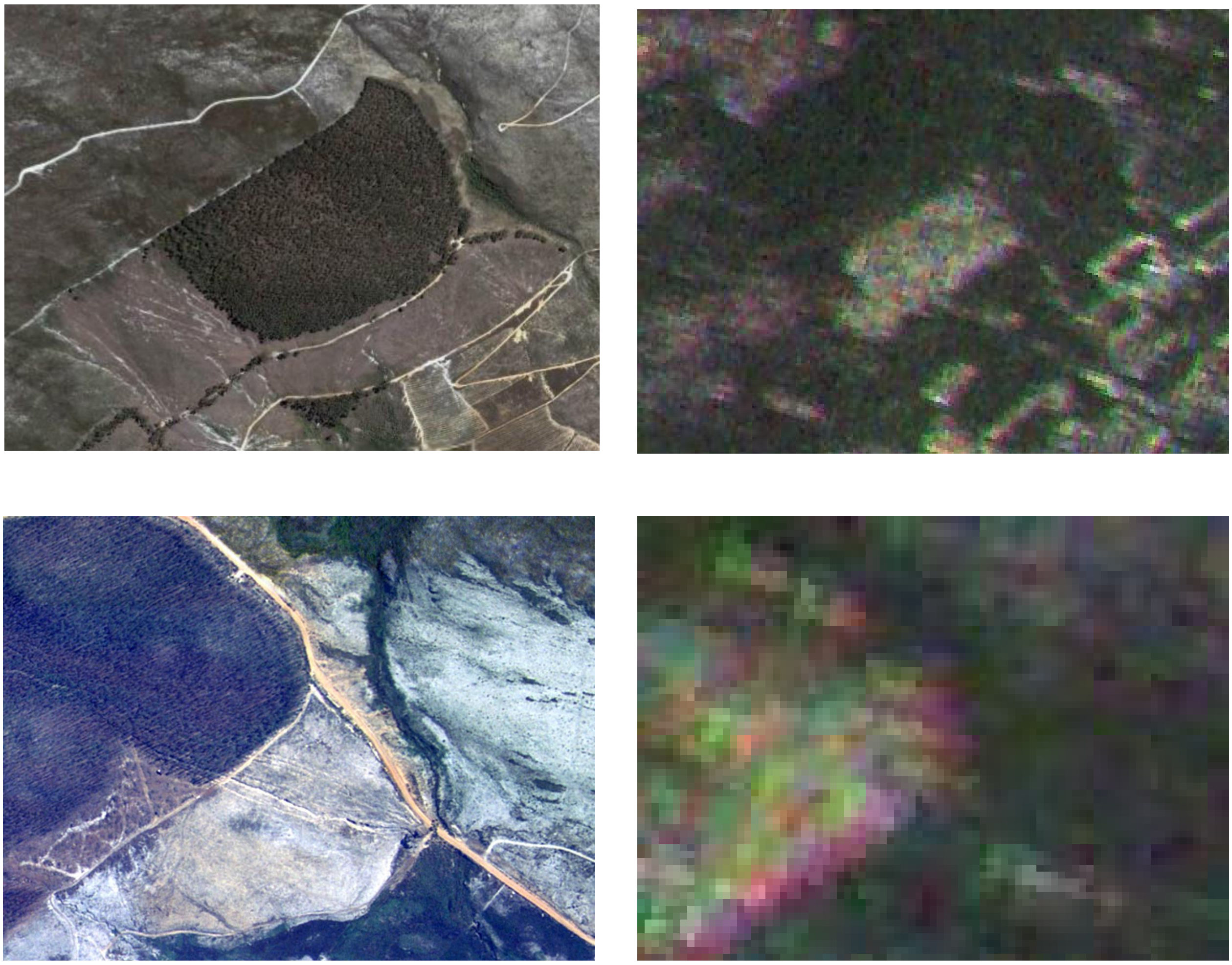

Figure 5.17: Forest area as seen by optical and SASAR. The forest appears as a bright square in the centre of the SASAR image (right).

Cultivated land

Cultivated land can easily be detected due to the boundary lines that separate each field. The fields are usually bounded by rows of trees. As we saw earlier these are easily detected be the SASAR sensor. The longer wavelength SASAR sensor has the ability to penetrate the surface of the vegetation canopy. It is also sensitive the moisture content of the soil. We can also investigate the different returns from VV polarised SASAR sensor and the HH polarised SASAR sensor.

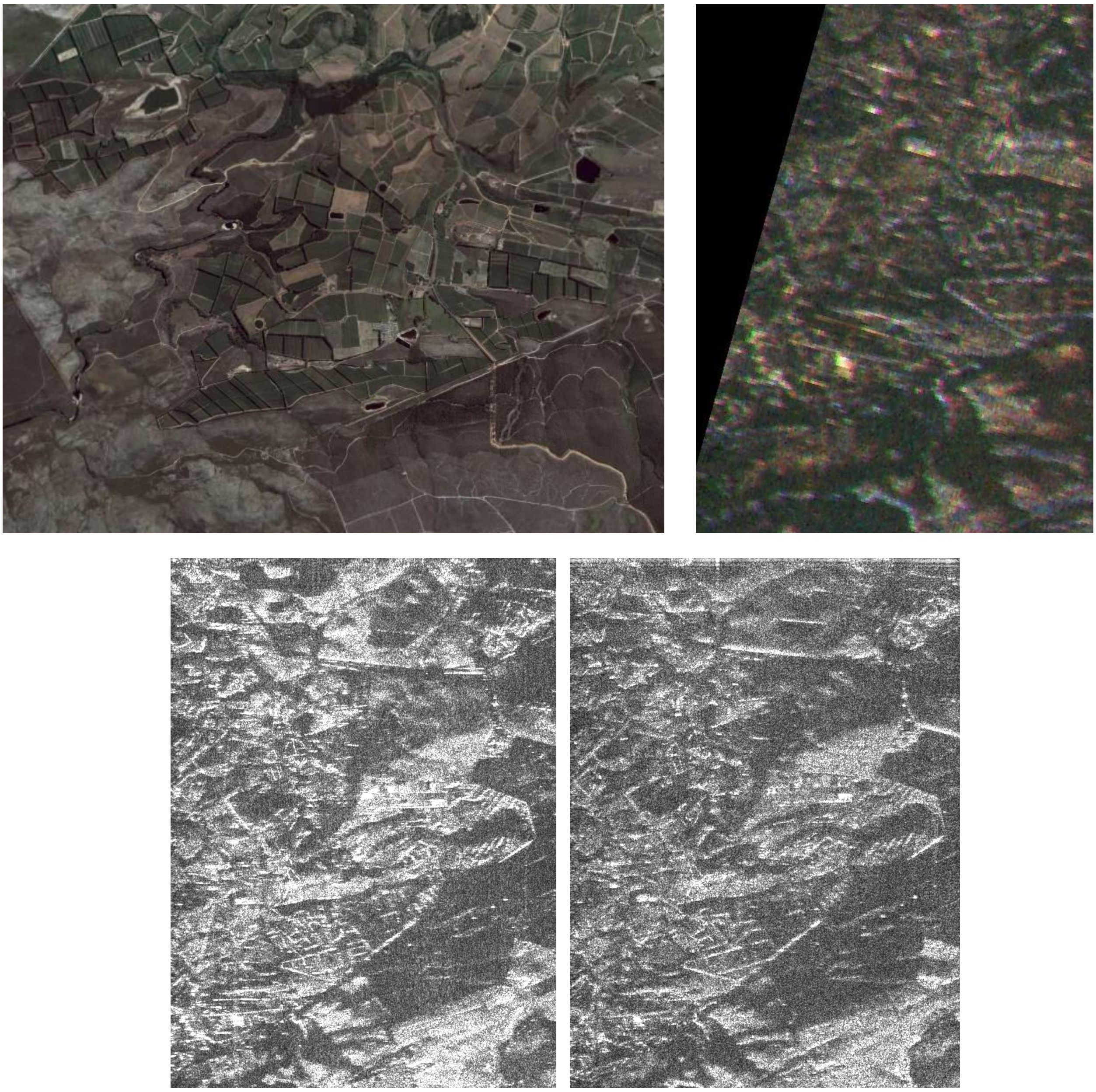

Figure 5.18: Cultivated Land. In the SASAR image (top right) the boundary lines appear as bright stripes. SASAR HH (bottom left), SASAR VV (bottom right)

There seems to be a stronger return from the HH polarisation. There may be attenuations resulting when the VV polarised waves interact with vertical stems of the vegetation.

Golf Course

The golf course is similar in concept to cultivated land The fairways can be identified due to the fact that they are lined by trees, hence, they create boundary lines. Figure 5.18 below shows the Arabella Golf Estate North East of Kleinmond.

Figure 5.19: Arabella Golf course as seen by Optical image top) SASAR image (middle) and ground photo (bottom)

5.2.2 WATER BODIES

The ERS sensor is superior to SASAR sensor for detecting water bodies. This is because ERS sensor operates at a higher frequency than the SASAR sensor (see Table 2.1 and Table 2.2) and ocean radar backscatter increases almost linearly with frequency [1]. Therefore it seems logical that any body of water would have better returns using the ERS sensor.

Estuary

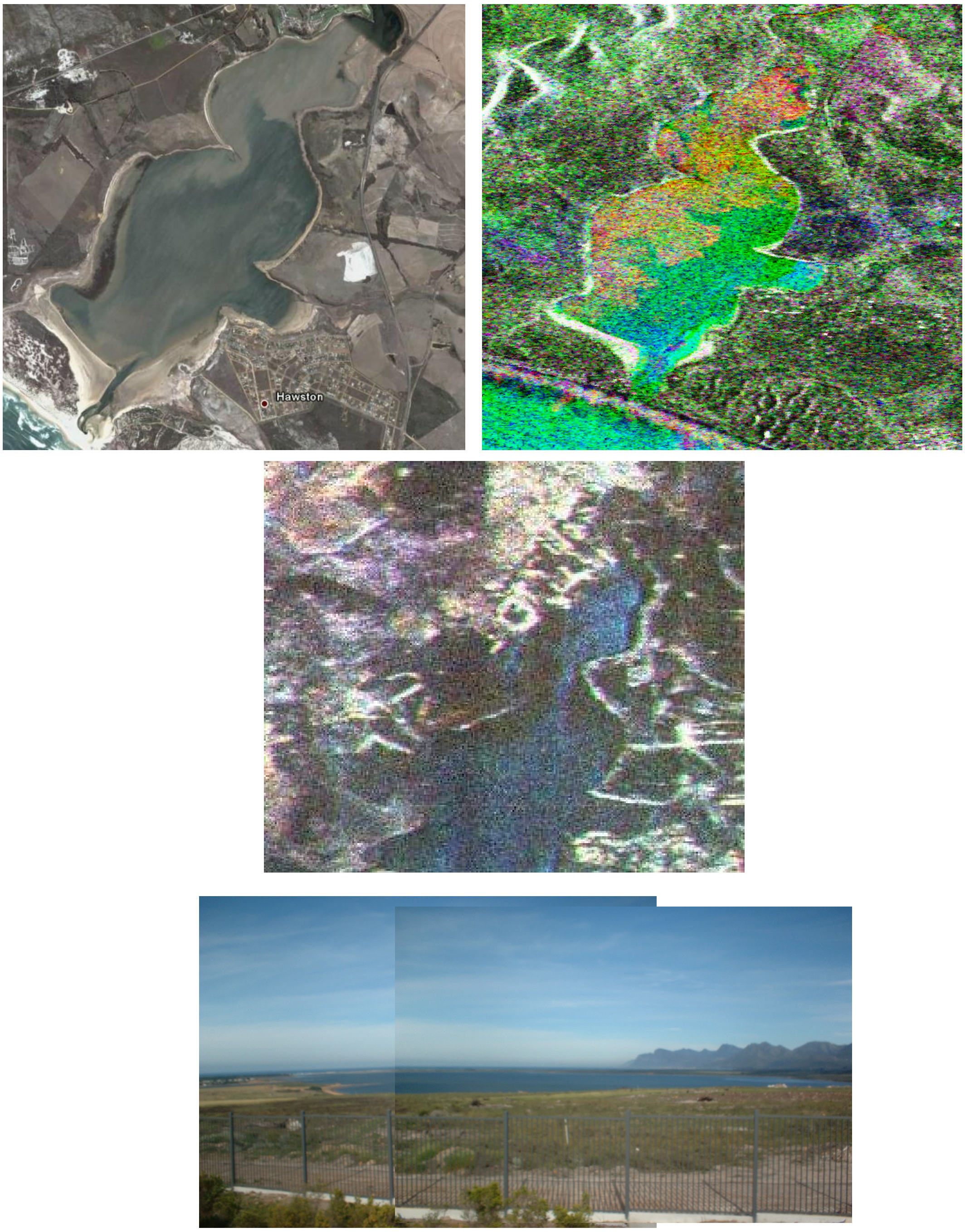

Figure 5.20: The Bot Rivier Estuary. Clockwise from the top left corner: Optical, ERS, SASAR VHF, and the ground photo (bottom).

The HH and VV polarizations of SASAR VHF and the IHS ERS image all show some interesting results with regard to Ocean backscatter.

VV polarization will provide more backscatter than HH polarization in calm seas. However, the difference between the returns decreases in rougher seas. Figure 5.21 below illustrates the difference in backscatter in the estuary a calm sea environment.

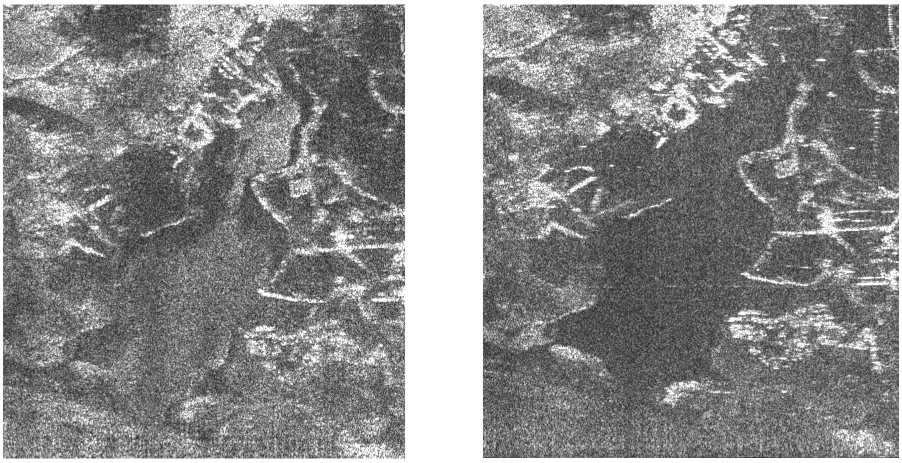

Figure 5.21: Backscatter from estuary. SASAR VV polarisation (left), SASAR HH polarisation right.

Figure 5.22 shows the IHS Transform of ERS image. The ERS sensor has VV polarisation. The IHS image shows the estuary and the ocean beyond where it is rougher conditions. See how the amount backscatter is influenced by the ocean conditions.

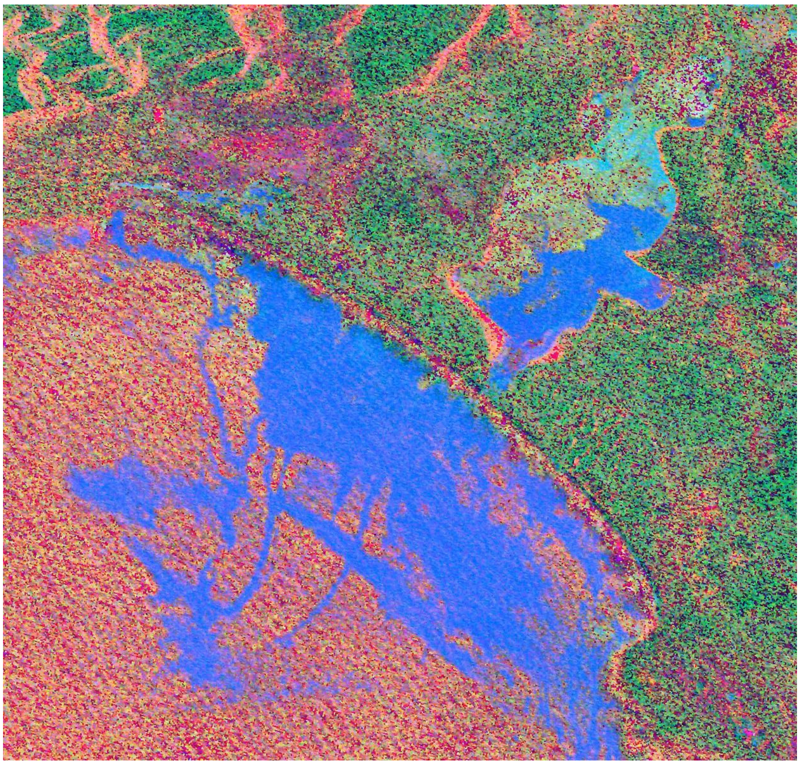

Figure 5.22: IHS transform of ERS data illustrating change in ocean backscatter.

Sea and Shore line

Figure below shows a section of the shore line between Kleinmond and the Estuary.

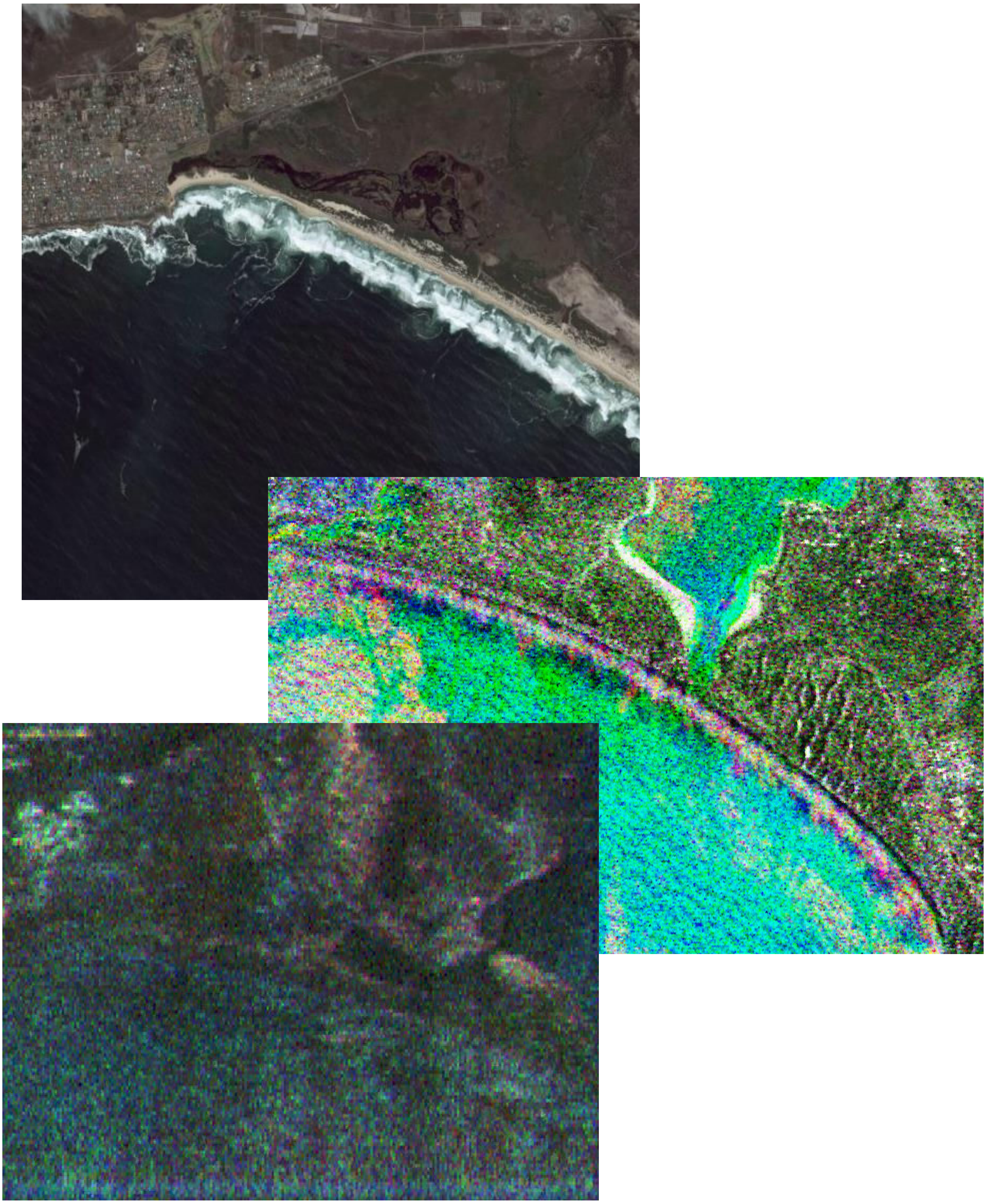

Figure 5.23: In these images we want to detect the shore line. Clockwise from the top right: ERS, SASAR VHF VV polarisation, Optical.

Dams

Figure 5.22 below shows two examples of small water bodies as seen by the SASAR VHF sensor and the ERS sensor. The top row is a small dam situated North of Hawston. The bottom row shows a dam located on the mountain side of Hermanus.

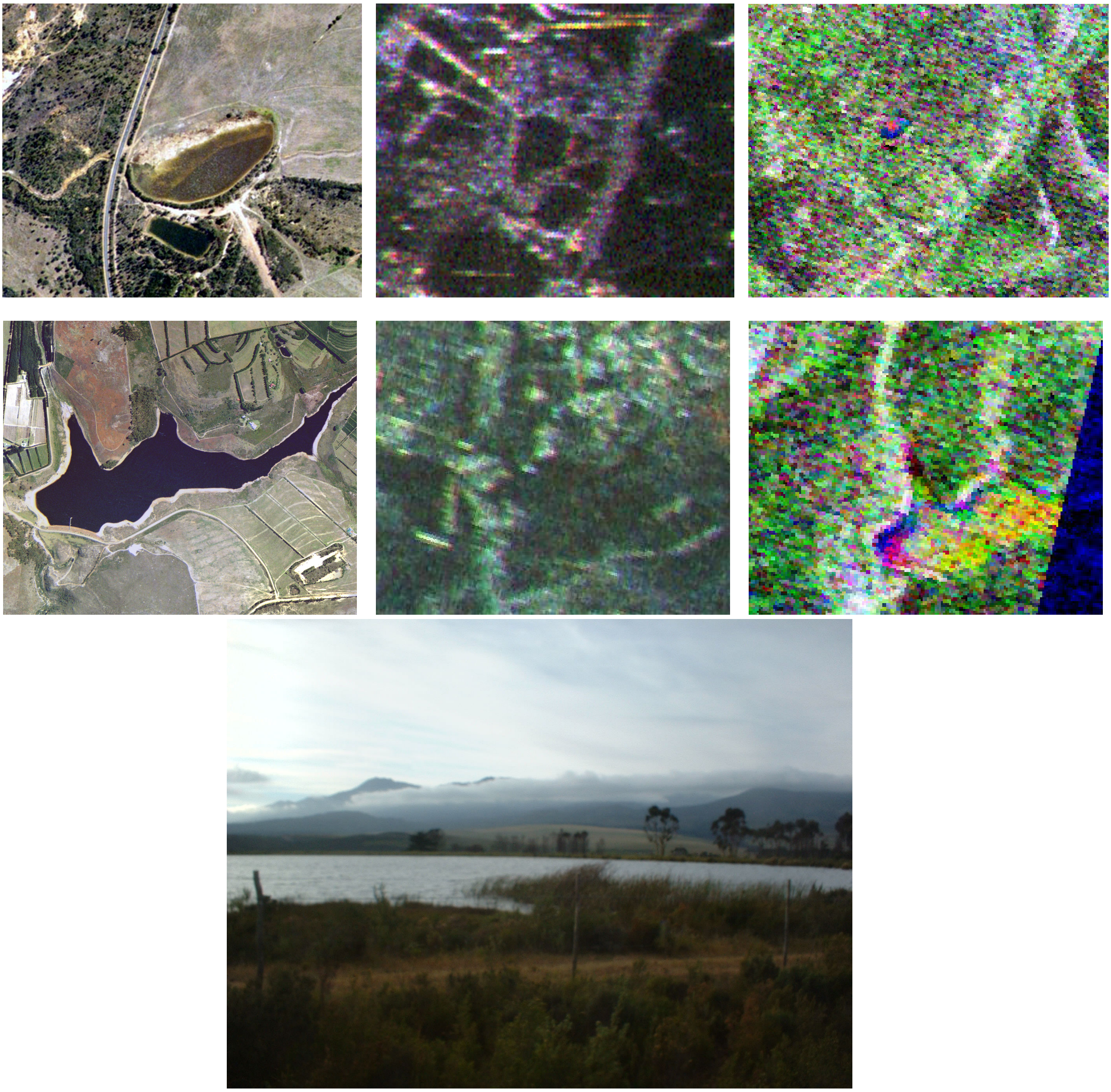

Figure 5.24: Small water bodies (dams). Images are in the order: Optical, SASAR VHF and ERS. The bottom image is a photo of the Dam in the top row.

5.2.3 RELIEF

The shorter wavelength of the c-band ERS sensor is less affected by the constructive and destructive interference caused by changes in the terrain. The c-band frequencies are sensitive to the changes of the terrain as they are occurring. For example ridges in the mountain side. [2]

Mountains

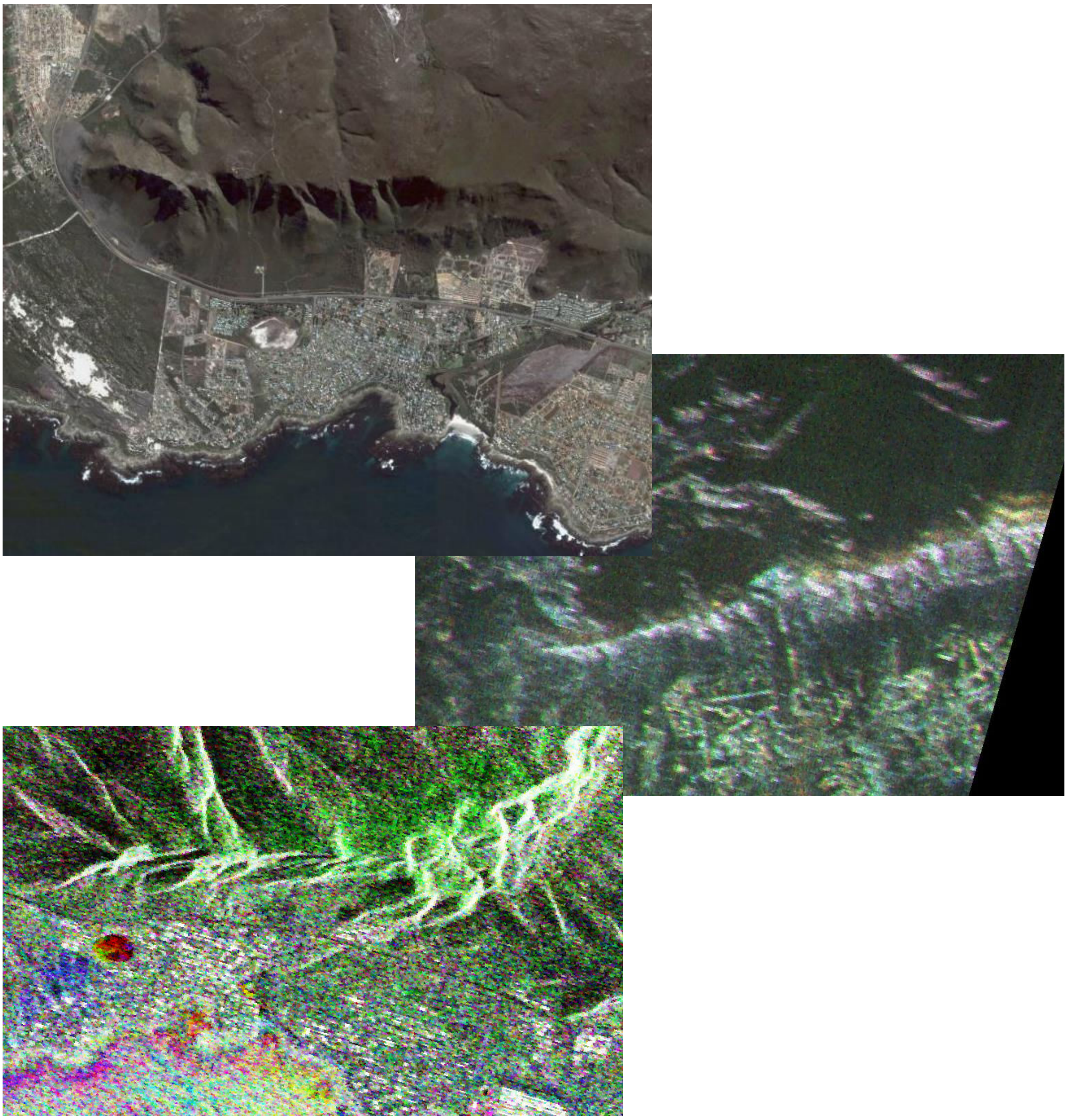

Figure 5.25: Mountain Ridge above the Town of Hermanus. Clockwise from top left corner, Optical, SASAR VHF, ERS

Ridges

The Ridges are situated in the Mountain side above Kleinmond. They can be identified easily in the ERS image. The lower frequency SASAR images are distorted by speckle and it is difficult to identify the ridges in the mountain.

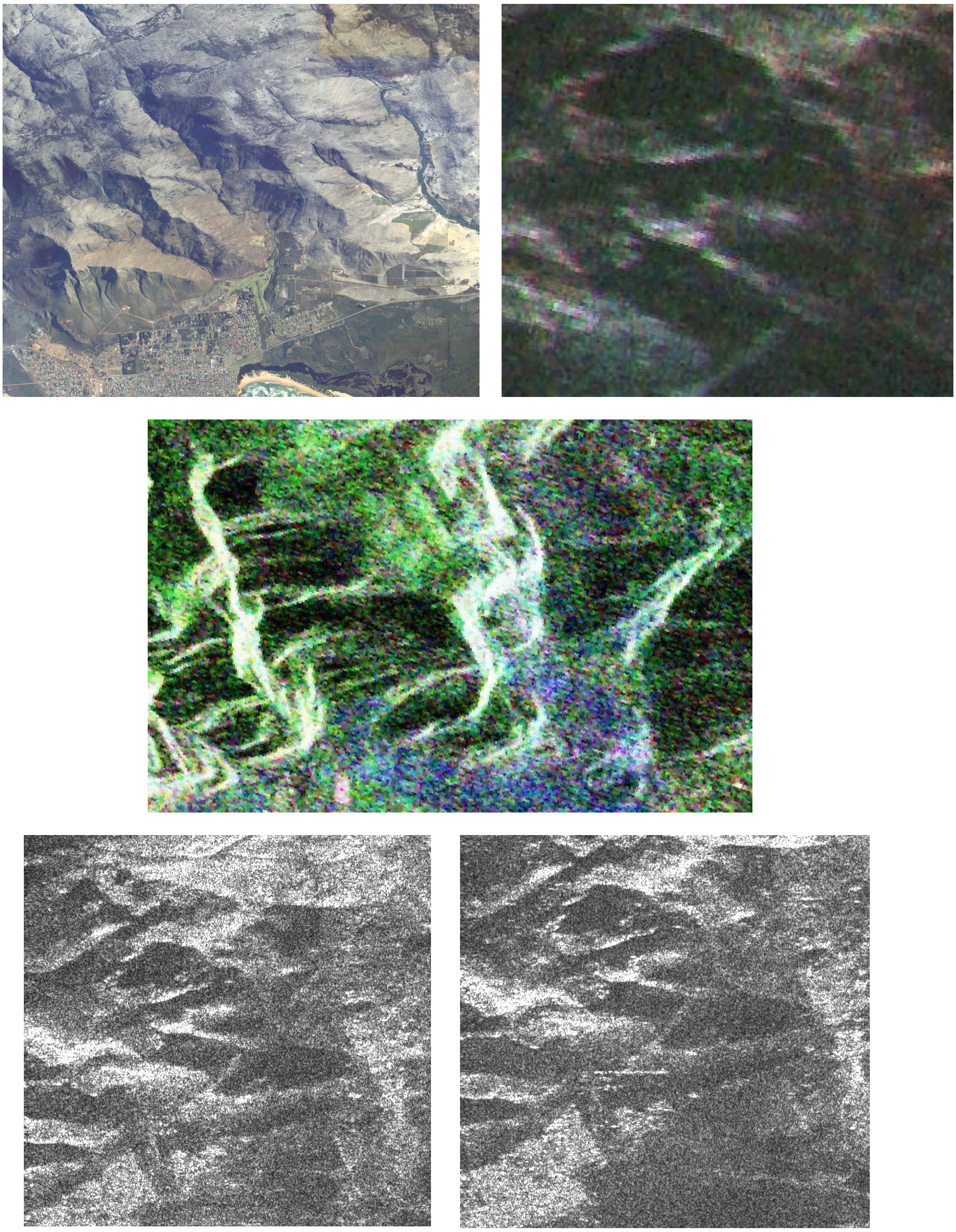

Figure 5.26: Large mountain ridges above Kleinmond. Optical (top left), SASAR VHF (top right), ERS (middle), SASAR VV (bottom left), SASAR HH (Bottom right)

There is little difference between the HH and VV polarization of the SASAR image

Ravines

Both Ravines are on the eastern side of the Bot Rivier valley. They are easier to identify in the ERS images. In the SASAR images they might be wrongly identified as vegetation boundaries.

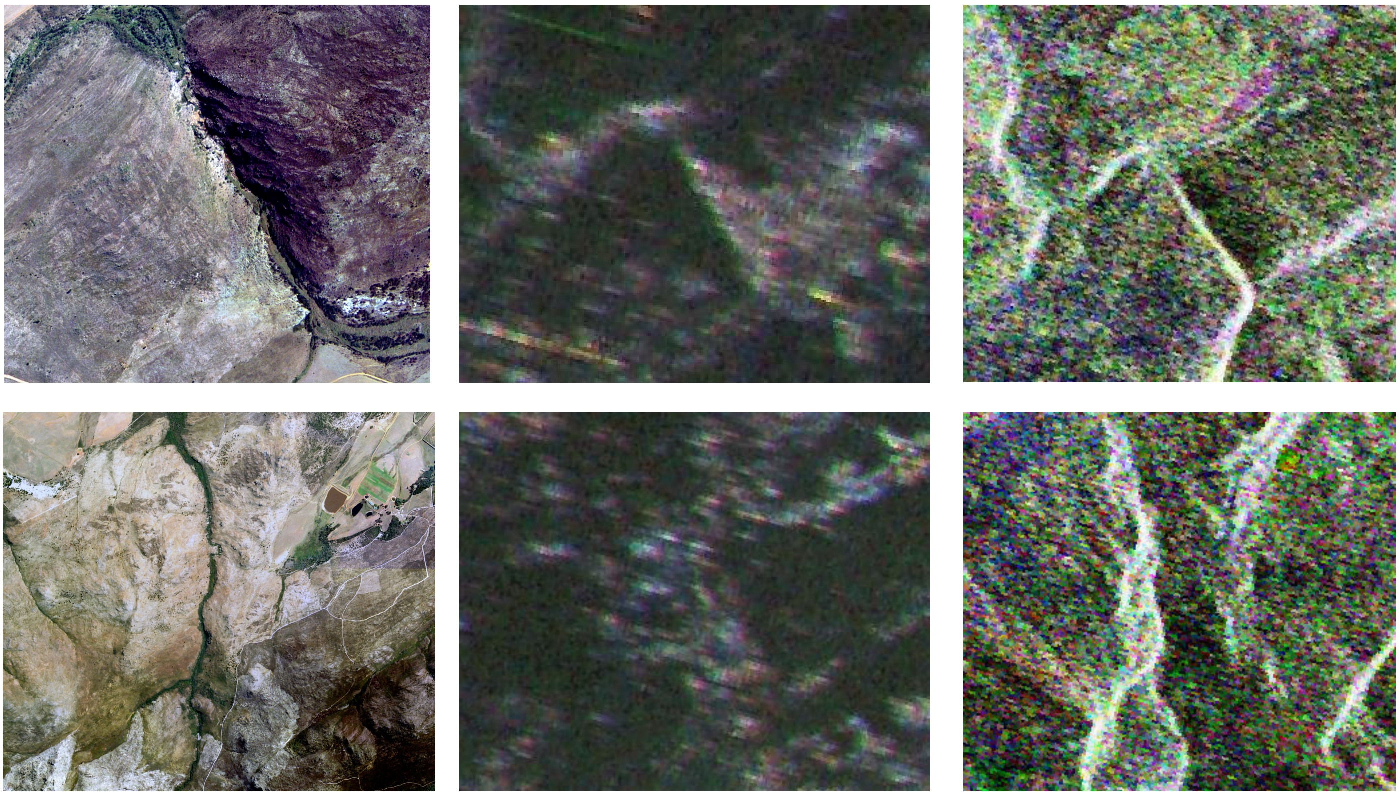

Figure 5.27 Ravines to the east of the Bot Rivier. The mages are in the order: Optical, SASAR VHF and ERS.

Granite Koppie

This particular granite Koppie may be easily confused with an individual building in the SASAR image. In the SASAR image the Koppie is circled in Red and an individual building is circled in yellow. This is the same building I looked at earlier in figure 5.4.

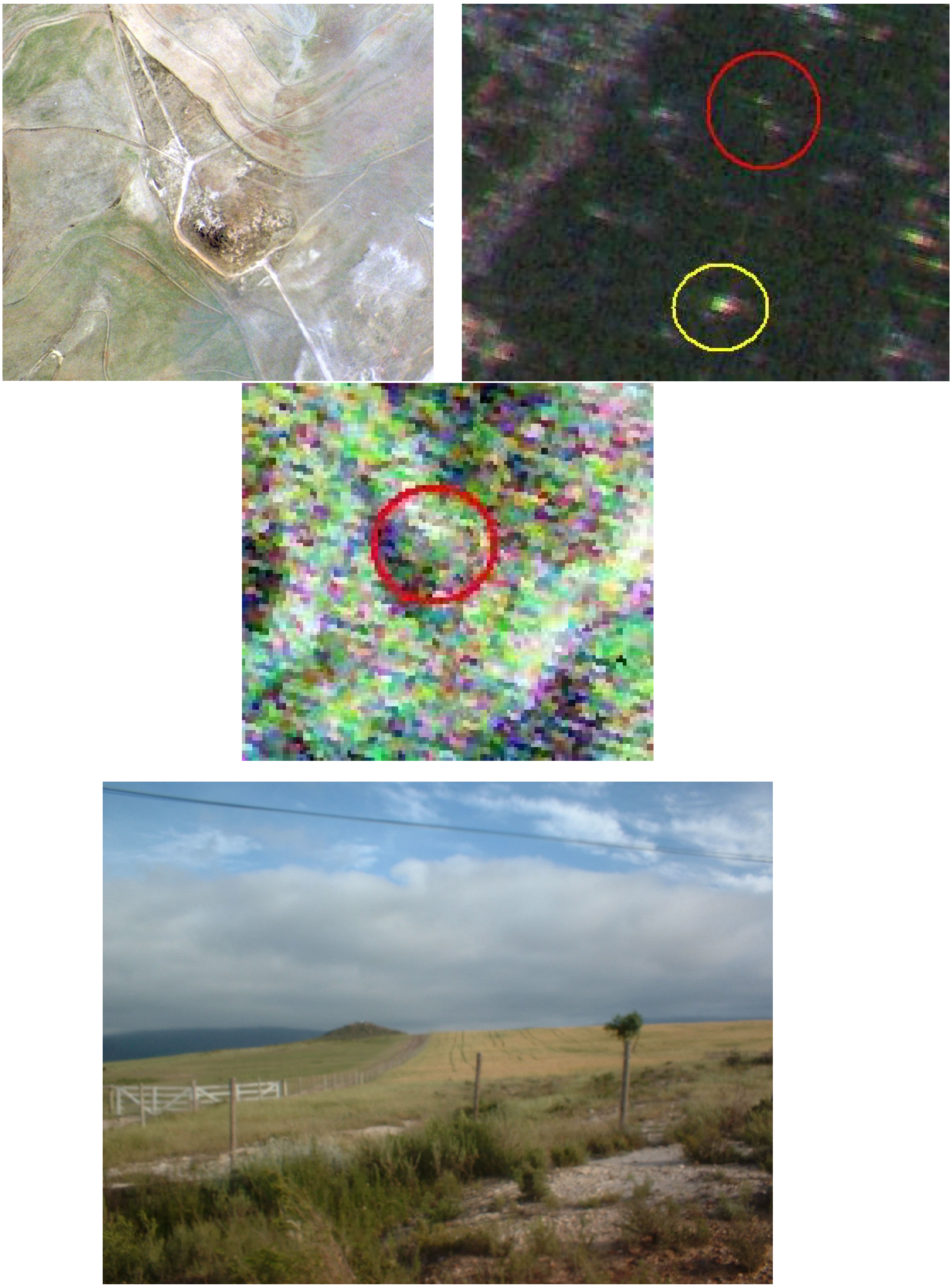

Figure 5.28: Granite Koppie North of the estuary.

6 CONCLUSIONS

I have drawn the following conclusions with regard to the relevant features.

BUILDINGS

Individual buildings are detected by the SASAR VHF sensor. They appear as bright spots (yellow/white) in the image.
A cluster of buildings is detected as a bright smudge in the image. The angle of the roofs relative to the flight path will have an effect on the return signal, hence, determining the brightness of the object in the image.
Neither individual buildings nor clusters are detected by the ERS sensor.

URBAN AREAS

Urban areas are detected by both SASAR and ERS sensors. Dense urban areas such as Hermanus are easy to detect in both the sensor images. However, less dense areas, for example Hawston, are more recognizable in the SASAR images. The ERS images have insufficient contrast between a sparse urban area and the surrounding vicinity making the urban area difficult to distinguish.

POWERLINES

The SASAR VHF sensor can detect power lines and Power line pylons. However, the power lines or catenaries are only detected when they are perfectly parallel to the flight path. They appear as bright stripes across the image. The Pylons appear as bright spots in the image. The spots tend to be Blue/white making the pylons distinguishable from an individual building. This is one of the biggest advantages of the SASAR VHF sensor as the power line pylons are impossible to identify in an optical image without initially detecting them in the SASAR image.

ROADS

Roads are detected by the SASAR VHF sensor if one or more of the following conditions apply:

- The road is lined by trees or some other tall vegetation.
- The road acts as a boundary between two different types of vegetation.

VEGETATION

Classification of vegetation is only possible with the SASAR VHF sensor. The c-band ERS sensor has a frequency which is too high to penetrate the surface volume. The SASAR sensor detects the ground cover and changes in the ground cover. The most prominent features are trees, rows of trees, clusters of trees and forests.
Cultivated land displays different tones and textures to the surrounding regions. It can be identified if fields are separated by rows of trees. HH polarisation showed stronger returns than the VV polarised SASAS VHF sensor.

I was able to identify the Arabella Golf Estate due to the fact that the fairways are lined by trees.

Vegetation can be confused with buildings as trees appear similar to individual buildings and forests appear similar to urban areas.

WATER BODIES

All bodies of water stand out clearly in the ERS images. The Bot Rivier Estuary, the Ocean and small dams are identifiable as particularly bright areas. However, in the SASAR image they are nearly undetectable. This is because ocean backscatter increases almost linearly with frequency. Naturally the ERS sensor is preferable for detection of water bodies.

An interesting finding is the IHS image of the ERS data. This showed a further enhancement of all water bodies. It also displayed interesting results with regard to the effect that polarisation has on ocean backscatter.

RELIEF

Most features of relief are better detected in the ERS sensor images. Mountains, ridges and ravines can be seen clearly in the ERS image. The short c-band wavelength is more sensitive to these types of changes in the terrain. Speckle in the SASAR images make it difficult to distinguish feature of relief.

There was however one exception. A granite Koppie was identified in the SASAR image but not in the ERS image.

A general recommendation can be made from these conclusions. The SASAR sensor is useful for detecting man made object such as power line and Pylons. The ERS sensor is appropriate for detecting natural feature in the landscape in particular water bodies and relief. I would not recommend either of the sensors for detecting vegetation or urbanization. The SASAR sensor can give rise to errors between these two features. The ERS sensor does not detect them accurately.

REFERENCES

[1] C. Elachi, “Space borne Radar Remote Sensing: Applications and Techniques”, IEEE Press, New York, 1988.

[2] D. Werle, “Radar Remote sensing training manual”, Dendron Resource Surveys Inc. Canada, 1988.

[3] T. Bennett, M. Lubbe, G. Doyle and M. Inggs, Study of SAR and Optical Imagery Of the Botrivier Area, Cape Town, 24th October 2005

[4] Wikipedia the Free Encyclopaedia, Principle Component Analysis.

[5] Timo Bretschneider, “Image Fusion in Remote Sensing”, Technical University of Clausthal.

[6] Lindsay I Smith, “A tutorial on Principal Components Analysis”, February 26, 2002

[7] http://staff.utia.cas.cz/zitova/registration.htm

[8] http://www.csir.co.za/plsql/ptl0002/PTL0002_PGE083_SUB_PROJECT?DIVISIONO=1000024&SUB_PROJECT_NO=10134

[9] http://www.crisp.nus.edu.sg/ers/ers.html

[10] http://www.deos.tudelft.nl/ers/

[11] T. Bennett, M. Lubbe, G. Doyle and M. Inggs “Processing and Georeferencing of available SAR and Optical Imagery of the Bot Rivier Area”, 5 July 2005

[12] Barbara Zitov, Jan Flusser, “ Image registration methods: a survey” Department of Image Processing, Institute of Information Theory and Automation, Academy of Sciences of the Czech Republic, 26 June 2003